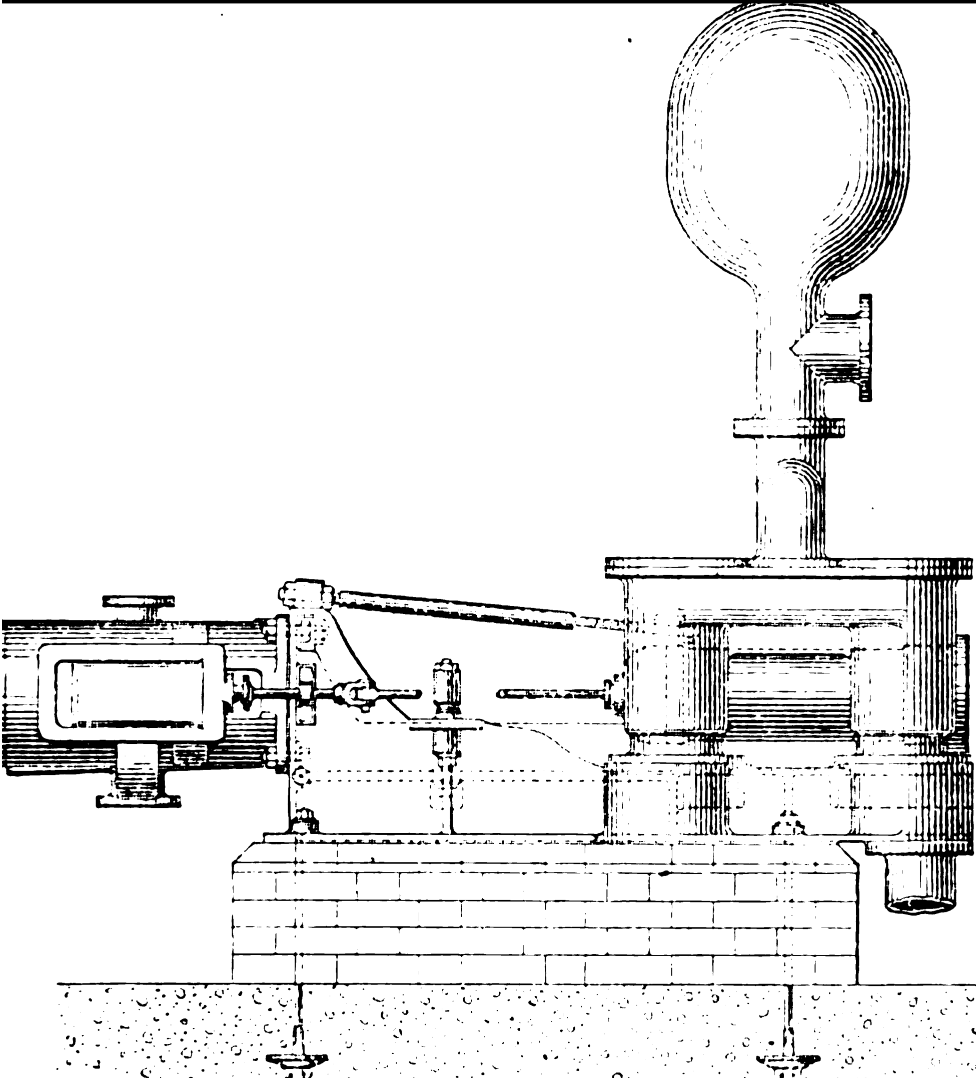

Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXXXVI.

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CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

20 *April*, 1886.

25 *May*, 1886.

Sect. II.—OTHER SELECTED PAPERS.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

CORRIGENDA.

Vol. lxxxiv. p. 426, line 14 from bottom, *for* "20 per cent." *read* "2 per cent."
„ p. 427, „ 5 „ *for* "Table III." *read* "Table II."
„ p. 430, Table V. in the last columns of the series (160°) the velocity given as "6·80" should be "6·18."
„ p. 432, line 3, *for* "0·01328" *read* "0·1328."
„ p. 446, „ 17, *for* "1826" *read* "1816."
Vol. lxxxv. p. 341, lines 18 and 22, *for* "staging" *read* "staying."
„ p. 396, line 9, *for* "Tuck" *read* "Suck."
„ p. 506, the name of the Author of the Paper on New Ordnance material should be "Bixby," and not "Bixley."
Vol. lxxxvi. p. 226. The positions of the letters G and H in the cut (Fig. 9) should be transposed.
„ Plate 8, Figs. 1. Diagram from engine, New Bedford W.W., *for* "12·83" *read* "15·83."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1885-86.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

20 April, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

(*Paper No. 2057.*)

"Brickmaking."

By HENRY WARD, Assoc. M. Inst. C.E.

IN hand-brickmaking, as now generally practised, some machinery is nearly always used in the preparation of the clay for moulding the bricks. So long as the brick is moulded by hand it is called a hand-made brick, even though, as with the Staffordshire marls, machinery is employed in the preparation of the clay, and in the pressing of the brick subsequent to its having been moulded by hand. In olden times all the operations of brickmaking were done by hand, including the digging and weathering of the clay; the tempering, the moulding, and sometimes the dressing after the brick was partially dried, though this last operation was seldom performed even with the highest class of bricks.

It is proposed, in the first instance, to describe the mode of brickmaking usually followed in the Home Counties, which is, in the Author's opinion, the best example of brickmaking by hand, though it has often been severely criticised. It may be remarked, that each of the systems prevailing in different parts of the country appears to have been gradually adapted, both to the materials at hand for making and burning the bricks, and also to the value of labour, transport, and such-like conditions, in the locality. The system adopted in the south of England is such that, practically, any clay can be made into bricks from the strong clay in the

north and in the south of London, down to that which is little more than sand, as in the Erith district.

The clay is first dug and carried to the wash-mill, where it is mixed with water in about equal parts by volume, and worked up to a thin slurry. In nearly all cases where stock-bricks are made, a chalk-mill adjoins the wash-mill. The chalk is also mixed with water and worked or ground up to a thin paste. Occasionally one mill is used both for clay and chalk, where the latter is soft and soluble. This chalk is run into the clay-mill, and there it is thoroughly incorporated with the washed earth. The chalk is added to the extent of 10 to 15 per cent. by volume, mainly for the superior colour it gives to stock-bricks, though it also acts as a flux or binding material, without which it would be impossible to make bricks out of some of the very sandy loams now used.

The slurry is mostly raised by elevators or pumps, so that it may run into reservoirs, technically called "wash-backs," about 100 feet square, and 5 or 6 feet deep. When the levels of the field will permit, the wash-mills are so placed that the slurry runs into the "backs" by gravitation. The backs are generally divided into two parts, in order that one part may first be filled, and the slurry in it may thus have more time to dry and be ready for use at the beginning of the season. Where the clay is free from stones, a layer some 3 feet deep is often wheeled direct into the backs before the washed earth is allowed to run in. This saves some of the expense of washing, and also allows the washed earth to become set, ready for moulding, much sooner than would otherwise be the case.

The advantages of washing the earth are great, and may be thus enumerated:—

1. The whole of the brick-earth (and chalk, where used) is thoroughly mixed; and this is important where, as is constantly the case, the clay varies greatly in richness.

2. Washing permits the use of brick-earth containing a large proportion of stones.

3. Where clay has to be transported a long distance to the backs, it is much cheaper to pump it through pipes than to convey it by any other means.

Though the clay is thoroughly mixed in the wash-mills, care must be taken to frequently move the point of discharge in the "backs," as the heavier sand has a tendency to sink, and does not flow so evenly over the "back" as the rest of the brick-earth.

The clay sinks and leaves the water on the surface, and the

latter is drawn off through an outlet in one of the banks forming the "back" farthest from the point of discharge into the "back." If the site and levels permit, the water returns to the wash-mill, and is used again. As the clay rises in the "back," the gap cut through the bank is gradually filled up with spits of clay. Drains are sometimes (though seldom) formed under the floor of the "back," to assist the water to drain away.

In the case of the very strong clays in London and the immediate neighbourhood, a layer of "mac" is deposited on the top of the clay in the back. This is simply sweepings from macadamized roads. It is used like sand to make the strong clays milder, and to such an extent that, in one brickfield arranged by the Author at Hampstead, as much as 33 per cent. of mac was required to be mixed in the clay to keep the bricks up to their proper size and shape, and to prevent them cracking. Where mac is used, little or no washed clay is admitted into the "back," though usually chalk-water is run on the top of the clay after it has been dug and has weathered.

When the clay has set in the "backs" a layer of sifted house-ashes called "soil" is spread over the top, 2 to 3 inches thick to every foot in depth of clay. Occasionally a thin layer of very fine coke called "breeze" is added to the house-ashes, but with an inferior result, as the heat is then too concentrated, and so often causes the bricks to run together when burning in the clamps.

The pug-mills are placed close to the "back," and by preference some 5 feet lower, so that the clay may be run into the pug-mills by barrows with as little labour as possible. The pug-mills are either horizontal or vertical.

Each moulder has one pug-mill and set of "hacks" under control, the whole being technically called a "stool." Occasionally double pug-mills are used to keep two moulders at work; but the single mills are preferable, as each moulder can then have the pug-mill placed most conveniently for his own "hacks."

All stock-bricks are sand-moulded; that is, the mould is dipped in, and thoroughly dusted with sand after the brick has been made. A moulder has about ten or twelve "hacks" to himself, each "hack" being from 90 to 100 yards long; therefore, as the bricks are stacked eight high, the hack-ground will hold about two hundred thousand bricks when full. The bricks, after becoming sufficiently hard, are all turned over ("skintled") to promote their drying. In summer the bricks are dry enough to put into the clamp about three weeks after moulding.

The clamp is made on the ground with first two layers of burnt

bricks, the bricks being spaced about an inch apart. This space is filled with the coarse ashes or breeze sifted from the fine ashes previously mixed with the clay. A layer also of coarse ashes, about 3 inches thick, is spread over the clamp below the green bricks, and occasionally thinner layers are spread between some courses of the bricks higher up the clamps.

The outside of the clamp is covered with burnt bricks, and the whole of the sides are daubed over with clay to make them air-tight. The clamps hold from two hundred and fifty thousand to three million bricks. Sometimes the fire is started at one end of the clamp, while bricks are still being stacked at the other end, more and more bricks being added as the fire slowly creeps along.

The burnt bricks are, as a rule, divided into three qualities: first come the stock-bricks, which are of a good colour throughout; then the grizzles, which have one side or end of good colour; and last the place-bricks, which are red all over, and soft, through being insufficiently burnt.

When a field is so small that there are only three stools in it, it still pays to have the wash-mills and pug-mills worked by horses; but with larger fields steam-power can be economically used. From seven hundred and fifty thousand to one million bricks per annum are made in each stool.

Two systems of driving-machinery are used in these brickfields, one by shafting, the other either entirely or partly by chains. In most cases where the field is fairly level and of regular shape, driving by shafting is the better plan. When there is but a small thickness of clay, and the field is irregular and uneven, driving by chains is convenient, as these can be led anywhere, and the pug-mills, and even wash-mills, may be changed from site to site as the clay is worked out, with very little trouble or expense.

Plate 1, Fig. 1, is the plan of a brickfield at Plumstead belonging to the South Metropolitan Brick and Lime Company. In this case all the wash-mills and pug-mills are worked by shafting. Owing to the irregularity of the levels, the shafting could not be taken in one straight line; therefore the pug-mills are placed on two different lines, connected together by an intermediate piece of shafting. The pug-mills are each 2 feet 6 inches in diameter, by 4 feet 6 inches long, with eight pug-knives on the shaft. The clay is tipped from a barrow into a hopper at one end, and is continually carried forward and discharged at the other end. The double pug-mills are a feet in diameter, and 5 feet 3 inches long,

and in these the receiving-hopper is in the middle, while the discharge is at either end; the knives are right-hand at one end and left-hand at the other. A wash-mill is shown, also a chalk-mill at *c*, and slurry-pumps at *d*. The wash-mill is about 24 feet in diameter, with brick sides and bottom. There is a revolving frame made up of a vertical spindle and eight tee-iron arms, tied together with wrought-iron rods, all driven by overhead bevel-gearing. Three heavy iron harrows, weighing 6 cwt. each, fitted with steel tines, are hung from three of the arms by chains, so that they may just clear the brick bottom, when the mill is empty, and rise and ride over the stones which collect in the mill often to a depth of 2 feet per day. The chalk-mill is about half the size of the wash-mill; it is placed at a slightly higher level, so that the chalk-water may run into the wash-mill. The slurry-pumps are ordinary three-plunger pumps, but made with doors to each valve, so that the valves are easily accessible for removing any obstruction. The "hacks" have movable covers or caps. In some cases fixed covers are used, but though they are better, the extra cost prevents their general adoption. Of the ash- or soil-ground (*h*), a considerable area is required for sifting the ashes. The engine- and boiler-house, *i*, is fitted with a 24 nominal HP. engine and a Lancashire boiler, the latter having a specially large grate for burning the coarser portion of the ashes, no coal being used. Sufficient power has been provided to allow for doubling the present number of stools. The shafting is driven at about 8 to 10 revolutions per minute by gearing; the pulley-speed is reduced by a pinion-and-spur, geared at a ratio of 7 to 1. A well-hole is fitted with a hoist for raising the chalk, which lies about 100 feet below the surface of the ground at this point, and is got by mining in underground workings, similarly to coal. The small chalk is used for the chalk-mill, while the large chalk is burnt into lime in a kiln. The speed of the pug-mill shafting, of 8 to 10 revolutions per minute, is a very uneconomical one. The Author has more than once proposed to alter it by running a much smaller shaft along the backs of all the mills at a speed of 50 to 60 revolutions per minute, using a pinion-and-spur at each pug-mill to reduce the speed. There is a prejudice against this, and it may even be a well-founded one, since some of the shaft-bearings are occasionally covered with clay; they often run without oil, and sometimes a piece of wood is substituted, with a groove cut in it for the shaft to lie in.

When the system of driving by chains is resorted to, chain-gear is erected close to the engine, and it is generally driven by a belt.

Plate 1, Figs. 3 and 4 show a good example of this gear. The number of grooved wheels is proportional to the number of pug-mills to be driven, though in some cases one wheel suffices for two pug-mills, the farther being driven through the nearer mill. This, however, should be avoided, as the driving-chain is very apt to slip. The chains can be led off at almost any angle in the horizontal or vertical planes, which is a great convenience, as they are often led over buildings and up and down hill. This chain-gear is driven through double-purchase gearing, the speed of the vertical shaft being 5 or 6 revolutions per minute.

In some fields the wash-mills and chalk-mills are also driven by chains. These are sometimes made entirely of iron, so that the whole can readily be moved from one site to another as the surrounding clay is worked out, and in this case there is no spur-gearing; the chain drives direct on to a pulley about 14 feet in diameter on the vertical shaft of the wash-mill.

Pug-mills driven by chains are usually of the upright kind, with a 5-feet chain-wheel on the top of the spindle, so that it makes about 4 or 5 revolutions per minute. This is very slow. Probably it was originally suggested as being about the speed at which a horse would turn the mill in walking round it. The chains used for driving are $\frac{7}{16}$ inch in diameter. These though heavy are not more so than is needed, seeing their speed is only 75 feet per minute.

The Author has employed this chain-gear not only to drive pug-mills and wash-mills, but also hoists and pumps in different parts of the field at the same time. To do this properly it was arranged to run the chain at about 250 feet per minute. In this case horizontal pug-mills were employed, but the pug-shaft was kept to a speed of 8 to 10 revolutions per minute by putting the chain-wheel on to a pinion-shaft, gearing into a spur-wheel on the pug-shaft.

As the wash- and chalk-mills are only kept going in the winter, and the pug-mills only in the summer, it has been the custom hitherto to run the chain much faster in winter, when driving the wash-mills, than in summer, and this is done by moving the strap-pulley from the double-purchase to the single-purchase shaft. Of course by arranging, as the Author has done, to keep the chain going at the quicker speed all through the summer and winter, it has been possible to use lighter chains. The chain is supported at intervals of about 15 yards by grooved pulleys, 7 inches in diameter placed on the top of posts 15 feet above the ground. The centres of the driving and driven pulleys should not be less than 130

feet apart, preferably 200 feet, and the chain should not be too tight. It drives better if allowed to sag some 5 or 6 feet between the posts. To prevent the chain slipping round the grooved wheels, six or eight V-shaped clips are bolted to the rims in which the chain may lie. Sometimes single clips are employed bolted on alternate sides of the groove, in order that the chain may be pressed, first against one side of the groove, and then against the other, thus assuming a slight wave-form. In one case the Author has seen the whole groove cast in this wave-form.

Referring to the system of washing the clay, not only does this prepare it in the best manner, and make it possible to use brick-earth, otherwise valueless; but at the same time by reducing it to the fluid state, it can be pumped long distances through pipes. This is a means of transport seemingly far cheaper than any other. It often occurs, that whereas it is most desirable to make the bricks at the water-side or by the railway-side, the clay to be used is a long distance away. Messrs. Taylor and Neate have kindly furnished the Author with a section of piping 1¼ mile long, through which slurry is pumped. The piping is 6 inches in diameter of the spigot-and-faucet kind, laid with lead joints. The clay is washed in a wash-mill, and is then pumped by two sets of three-throw pumps, to either one of two brickfields. These pumps are each 8 inches in diameter by 18 inches length of stroke, and are driven at an average speed of 22 strokes per minute, producing a pressure in the pipes adjoining the pumps of 50 lbs. per square inch. To cleanse the pipes and to prevent them choking by the settling of sediment, every night, before stopping work, for about twenty minutes, clean water only is pumped. This forces out the slurry in front. The water is then allowed to drain out of the pipes, by opening valves at the lowest points, and also by opening air inlet-valves at the highest points, to prevent damage by frost.

Hand-made red-facing bricks are manufactured from clay generally sufficiently free from stones to render it unnecessary to wash it. After being weathered in the winter, this is pugged, moulded, and dried, similarly to the stock-bricks. The red-bricks are burnt in kilns, and these are of various types, sometimes a plain "Scotch kiln" is used, sometimes an open-top kiln, and at others a closed-top kiln. In the last two cases the fire-holes are under the floor of the kiln, and they are fired either from the end or from the side. The floor is perforated for the fire to come through, the whole forming what is known as an up-draught kiln. These kilns are made to hold from ten thousand to fifty thousand bricks. The largest brickmakers in the kingdom are Messrs. Smead, Dean

and Co., who make about eighty million annually. Mr. Dean has invented a new mould for bricks, constructed entirely of thin steel plate in place of the old mould made of wood and iron. The new mould is about 1 lb. lighter than the old one. As the workman lifts it four times in moulding each brick, and he makes eight thousand to nine thousand bricks daily, the advantage in reducing the weight of the mould is very great.

Turning now to bricks made entirely by machinery, there are many different systems, and it is difficult to draw any clear dividing lines, except between the two distinct classes of plastic bricks and of dry or semi-dry bricks. The latter differ from the former in that they are made so dry that they can be run direct into the kiln from the machine without previous drying, and can be stacked as many as thirty bricks high at once. All clays can be manufactured into plastic bricks, but only a small portion of them can be made into semi-dry bricks, as for these the clay must be of a marly or shaly nature in order to be ground to small particles. In the mining-districts, and in the North of England, suitable shales and marls are plentiful; in the South, excluding the West, there are only three or four semi-dry brickmaking works. Various attempts have been made to get the more plastic clay through the perforated bottom of the pan-mill. Burnt ballast or ashes have been mixed with the clay, and it has even been partially dried on hot floors before being put into the pan-mill. No practical success has been met with. The perforations in the pan should not be larger than $\frac{3}{16}$ inch in diameter if round, or $\frac{1}{16}$ inch to $\frac{1}{8}$ inch broad if oblong, otherwise the quality of the brick suffers. So long as the clay can be got through the perforations, the wetter it is the better, though the clay should not be wetted afterwards as it would clog and not drop into the mould from the feeding-box. Some shales are so dry that water is added, through a perforated tube, during the grinding in the pan-mill. A rough test as to whether the clay is damp enough, is to take a handful when ground, and squeeze it, when it should adhere and form a ball.

Probably the two greatest difficulties to contend with in semi-dry brickmaking are to grind the clay small enough, and to get it equally moist. Generally 5 inches in depth of loose ground clay in the mould will compress to a 3-inch brick; but there is always an arrangement by which the 5 inches may be increased or diminished, by adjusting the position of the lower piston in the mould during the operation of feeding. This adjustment is a difficulty; it must be varied perpetually, both according to the size

of the particles of the clay and to their state of dryness. The drier the clay the less is required to make a brick. In the older type of semi-dry brick-machines the top piston simply dropped on to the clay in the mould, or was forced on to it by steam-pressure, as by a steam-hammer. If therefore there was too much or too little clay in the mould, the resultant brick was either too thick or too thin, though it was always subjected to the same pressure. In the machines for semi-dry bricks built now-a-days the two pistons have positive movements; thus the brick is always the same thickness, since when giving the final pressure the pistons are always the same distance apart. The clay is often either too little pressed to make a good brick, or too much pressed for the safety of the machine. Two holes are usually left in the top piston, through which any superfluous clay should be squeezed. In actual practice, these holes constantly get plugged with dry clay, and do not act as a safety-valve as intended. It is impossible to feed the clay to the machines constantly in the same state of dryness, or to ensure the particles being of the same size. When the clay is discharged on to the first floor from the elevators, the larger particles drop on the top of the heap of ground clay, and separate themselves from the finer particles by rolling further away. There is generally an attendant to feed the clay into the shoots leading to the machines, or to superintend this being done automatically; still, it is impossible to get equal feeding. In the same way even though all the clay be delivered from the pan-mill equally moist, some of it, owing to its being ground overnight, or, to rolling to the outside of the heap, gets drier than the rest. Thus, the measurement of the clay in the mould wants perpetually adjusting, and at best the bricks must vary in quality. The layer of 5 inches of loose clay is compressed into one of 3 inches, therefore nearly 50 per cent. of the original bulk is air. It is difficult to get rid of this air, but it is generally done by working the machine slowly, limiting the number of bricks made per minute to some fifteen per mould, so as to give time for the air to escape; and it is also done by giving two distinct pressures to each brick, with a slight interval of time between. The second pressure is sometimes obtained by transferring the brick to a separate press, which the Author thinks preferable. It increases the cost slightly, but the brick is of superior quality, partly owing to plenty of time being allowed for the air to escape, and partly also because the press-mould can be kept in much better order than the machine-moulds, as the latter bear the brunt of the work. The wear-and-tear of the moulds and pistons is

considerable, especially in gritty shales. A mould has been known to wear out in two or three days.

Where a brick has been subjected to too much pressure, if this be possible, it is almost sure to crack along its face when relieved from the pressure, owing to the escape of the compressed air, which has been shut up inside the brick. Those bricks, however, which are cracked in the machine, if repressed become the best.

In manufacturing semi-dry bricks, to be afterwards treated in a separate press, it is well to make them with a deep frog or recess in the centre, leaving a wall ½ inch thick, standing all round the brick as much as ¾ inch high. When this is pressed, a good face is made, as the outside of the brick is squeezed harder than the inside. In completing the brick at one operation, the clay has a tendency to flow from the outside to the centre of the brick, owing to the friction of the sides of the mould, and thus to make the face less pressed than the inside of the brick.

All the pistons of semi-dry brickmaking machines are kept hot by steam circulating through them. The Author does not know to whom this invention is due, but it is a most important one. The heat forms a film of vapour, from the moisture in the clay, on all the metal surfaces, which acts as a lubricant, and enables the brick to leave the mould and piston with clean sharp edges. Should the steam be shut off by any accident, the clay at once adheres to the metal surfaces, and it is impossible to proceed with satisfaction.

Plate 1, Fig. 2, is a plan of the works erected by the Author for the Kent Brick and Tile Company, at Pluckley Station near Ashford, Kent, at a cost of £25,000. The works are connected with the main line of the South Eastern Railway by a siding; *a* is the engine and boiler-house, with machine-house adjoining; *b* is the "Hoffmann" kiln, capable of burning about one hundred thousand bricks per week; *c* is the hack ground for drying the plastic bricks; *d d* are the drying sheds, used principally for blue bricks. These sheds are heated by the exhaust-steam, when the engine is at work. At night live-steam can be blown under the sheds, if it be necessary to work them at the maximum output; *e e* are four Staffordshire kilns adjoining one another; *f f* are two other Staffordshire kilns; *g g* are Scotch kilns for burning those bricks which are dried on the hack grounds; *h* is the main line of the South Eastern Railway; *j* is a siding from the same, leading to the works. This siding is divided into two, the branch *k* being kept on the ground-level, to allow the coals for the boiler and kilns to be brought in conveniently; while the branch *l* is

kept about 3 feet below the general surface, that the bricks may be loaded more easily. The floor of the trucks is about level with the floor of the kilns; *m m* is the clay hole, from which the clay is hoisted to the first floor of the machine-house, by an incline 1 in 5.

The clay is loaded into wagons, each containing about two barrow loads. These wagons are carried on four cast-iron wheels, or disks, about 9 inches in diameter by $\frac{3}{4}$ inch broad, fitted with steel axles 1 inch in diameter. Each axle has one wheel fast, the other loose, thus there is no wear in the bosses of the wheels, except that due to the slight differences of motion of the two wheels, when passing round curves. The advantages of these small wagons over larger ones are: (1) that as the clay varies, in different parts of the clay-hole, a good mixture is effected by using wagon-loads from each part in rotation. (2) As there is a constant stream of small quantities of clay, the mills must be fed a little at a time and often. This saves the break-downs, frequently caused by tipping large wagon-loads bodily into the mill. (3) The wagons are light and handy, so that a boy can manipulate them, slewing them anywhere on the cast-iron floor-plates, and finally turning them over when discharging them. A flat wrought-iron strap, $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch, projects 4 inches above the top of the wagon with a vertical V-groove cut into it. A $\frac{9}{16}$ inch continuous chain is used for hauling, any vertical link of which will lie in the above groove, while the next horizontal link bears against the strap and does the hauling. The weight of the chain keeps it in place in the groove, but the wagons should not be less than 15 feet apart, otherwise they may slip, owing to the chain jerking out of the groove. The rails used are angle-irons, with a very small vertical flange, the gauge being 10 inches only. The endless hauling-chain *n n* passes round a 5-feet grooved pulley, on the vertical shaft of the hoisting-gear in the machine-house at the top of the incline, and round a similar pulley, on a vertical shaft at the bottom of the incline. Two or three other horizontal pulleys are fixed on this lower vertical shaft, from each of which endless-chains are led to similar pulleys and shafts at the working faces of the clay-hole. The full wagons are thus brought along rails from the face of the clay, to the bottom of the incline. Here a boy transfers them to the chain working up the incline. On arriving at the top the wagons disengage themselves from the chain, and after being tipped, are engaged with the return chain and sent to the bottom of the incline, and thence to the clay-face by another chain. The hoisting-chain usually travels about $\frac{1}{2}$ mile per hour. By using cone-pulleys for driving the hoisting-

gear, the speed is easily reduced or increased, as more or less clay is required.

Both semi-dry and plastic brickmaking machines are used in the machine-house. Everything is driven from a line of shafting extending from end to end of the house, and running at about 100 revolutions per minute; and all the clay is brought into the machine-house on the first floor. The semi-dry bricks, after being made and pressed, are run direct into the Hoffmann kiln.

Plate 1, Figs. 5 and 6, represent the pan-mill 9 feet in diameter. This mill is used exclusively for preparing clay for the semi-dry machines. The inner circle shows the solid bottom of the pan on which the rollers run, while all the plates in the outer circle, marked *b b*, are pierced everywhere with fine perforations. The crushed material is then swept from under the rollers on to the perforated plates forming the outer circle, by a plough, fixed to the cross-arm. Those particles which are too large to drop through the perforations are carried back under the next roller by a similar plough or guide.

After the clay has passed through the perforated bottom into the lower pan a rotating arm sweeps it into an elevator, by which the clay is raised to the first floor of the building. It is then passed down through shoots to three Chamberlain's semi-dry brick-machines, and thence to three power-presses.

The Chamberlain machines, though they did good work, were complicated, and needed much repair. They are not made now, and those at Pluckley have been altered, until they somewhat resemble the machine represented in Figs. 7, 8, and 9. These show the machine constructed by Messrs. Whittaker and Co., of Accrington; and, as it is, in the Author's opinion, one of the best machines, he has selected it for illustration. It produces two bricks at one operation, or a total of about one thousand five hundred per hour. The powdered clay is passed down a trunk to the feed-box of the machine. This slides over the moulds, fills them, and returns under the trunk. The upper piston then descends suddenly, the rollers on the connecting-rods having fallen down the straight part of the cam which is on the crank-pin. The slot in the connecting-rod allows this operation, and thus the full weight of the cross-head, pistons and rods, compresses the clay. Time is given for the air so compressed to escape before the final pressure is put on. This is not done until the crank-pin is passing the lowest point; yet this final pressure lasts for one-twenty-fourth of the whole revolution, as the actual vertical move-

ment is only $\frac{1}{3}$ inch during this period. The pressure on the lower pistons is received by the steel cam-shaft, the overhanging portions of which carry the driving-wheels. Cams are cast on these wheels to actuate the levers, giving motion to the feeding-box. It will be seen that the whole strain is taken by the cam-shaft and connecting-rods, the framing carrying only the ends of the shafts. After the brick has been pressed, the action of the central cam lifts up the brick and lower piston level with the table. The front of the feeding-box, on its forward movement, pushes the brick off the piston. This immediately afterwards, by the action of the cam, drops suddenly, until it is arrested by the balance-lever, ready to receive a fresh charge of clay. The position of the balance-lever is adjusted by a screw, worked by the attendant, and this is altered just as the clay varies in moistness or in fineness of grinding. When the feedbox has moved backwards, the upper piston falls as above described on to the clay, and carries it, the lower piston, and the balance-lever down, until they meet the cam, when the final pressure is given. The lower piston has a large roller fitted to it, against which the cam works, and the whole is protected by a hood from the clay that would drop on it.

The plastic brickmaking machine at Pluckley was made by Messrs. Middleton and Co. It consists of one pair of slow-running hedgehog rollers, into which the clay, after being well watered in the clay-hole, is tipped from the wagons. The clay passes through a second set of quicker running smooth rollers, set much closer together, from whence it drops into a horizontal mixing-trough, fitted with knives, similar to a pug-mill, except that it is open-topped. Should any further water be required, it is added to the clay here, through a perforated pipe, fitted along the trough. The trough discharges the clay into a vertical pug-mill. It is forced from this, in a continuous but ragged stream, through a hole at the bottom. It is here taken, on small carrying-rollers, to two large compressing-rollers 18 inches in diameter, which force it through a Murray's die, in a stream of the same section as a brick, on to a Murray's cutting-table.

Fig. 10 shows a complete machine, as made by Messrs. Clayton, Howlett and Venables, for dealing with rough clays and marls, such as are found in Staffordshire, and from which the blue bricks are made. It consists of a double crushing roller-mill, a horizontal mixing-mill, and a brick-machine. The marls are passed through the crushing rollers dry, without previous soaking with water; the mixing with water takes place solely in the mixing-mill after the crushing. The upper pair of rollers run slowly,

and are set about $\frac{3}{4}$ inch or 1 inch apart. They have longitudinal strips on them, to enable the clay to be better gripped. The lower pair of rollers are smooth, and set only about $\frac{1}{4}$ inch apart, and consequently have to run much faster to press the same quantity of clay as the upper ones. All rollers have scrapers working against them, usually held up by weighted levers. The brick-machine has a pair of rollers mounted on the top of the pug. These are set close together, and force the clay into the horizontal pug under pressure. The pug-mill is fitted with the ordinary knives, except at the end. Here one turn of a screw-blade is fixed on the extremity of the pug-shaft, in order to get the pressure necessary to force the clay through the gradually reduced end of the cylinder, until it issues from the mouth of the die in the form of a brick on to a cutting-off table.

The Author has used a primitive safety appliance for driving the crushing-rollers, in many cases with success. It is impossible to prevent hard stones, pieces of old iron, &c., getting between the rollers. It is better, therefore, to have some means by which the otherwise certain breakage may be avoided. The driving-pulley is loose on the shaft, but drives the shaft through a wooden pin fixed to a lever or arm keyed to the shaft. A wooden pin is turned down as a trial until it just breaks with ordinary work, then a pin twice as strong is substituted. A number of similar pins are kept in stock in case of breakages.

The cutting-off table, where the stream of clay is divided into bricks, is a very important part of the plastic brick-machine, and most of the tables now made are very similar to that invented by Mr. Murray some sixteen or eighteen years ago. The stream of clay is continually issuing from the die, and when it becomes of sufficient length to form ten bricks, it is cut off by a single preliminary wire. The block of clay is then pushed still further forward by hand on to the zinc-covered table, which is kept well oiled with black oil. A lever through a rack-and-gearing forces the block of clay through the eleven wires, forming it into ten bricks, with a waste piece of clay at each end. The bricks are received on a loose board, which is at once lifted bodily on to a barrow, while another loose board is put in its place. The use of a loose board is a great advantage, as it enables ten bricks to be moved at once instead of being handled singly, thus the output is largely increased.

Mr. Pinfold, of Rugby, has devised a cutting-off table very similar to the foregoing; although a little more complicated, it has the advantage that the bricks are cut from the stream of clay,

while travelling, and so one of the waste pieces at the end of the block of clay is saved. This is done by mounting the whole table on small wheels and rails to enable it to have a free longitudinal motion while the wires are cross-cutting the clay. The table is pushed under the stream of clay, where it is held firm, until sufficient clay has been received upon it to cut into the required number of bricks. The table is then left free, when the continually travelling clay carries it along, while the attendant forces the wire through the clay. The bricks are received on to the usual loose board, and the table is again pushed under that portion of the stream which has in the meantime been left without support, owing to the table having been carried away from under the die.

Probably the most important part of the plastic brick machine is the die, inasmuch as it is absolutely essential to have a stream of clay perfect in shape. Much ingenuity has been expended in devising an immense number of different forms of dies, often apparently without duly appreciating the problem to be overcome. It is frequently seen that a die which will answer perfectly for the clay in one field, will fail for the clay of the field adjoining. No doubt the flow of a plastic material like clay follows very similar laws to the flow of a glacier or of water in a stream, complicated, however, in the case of clay by the fact that different clays have very different coefficients of friction. When a stream of clay, having about the sectional-area of a brick, is forced through a simple hole, the centre of the stream flows faster than the ends and corners, and these, therefore, become ragged and broken. This can be obviated in two ways, either by putting friction on the centre of the stream to retard it, as is practically done very successfully when perforated bricks are made, or by so reducing the friction at the ends and corners, that all parts of the clay flow with equal velocity.

This latter principle is the one sought to be carried out, in Murray's die (Plate 2, Figs. 11 and 12). The ends or sides of the die are made loose, and are held in place by set screws. The inside faces of the ends are made with vertical grooves, and these are covered with moleskin, which can be readily renewed from time to time. The grooves are connected by pipes with small watertanks. The moleskin is thus kept wet, and so lubricates the sides only of the stream of clay. As the nature of the clay may require, more or less lubricant can be supplied by raising the tanks to give a greater head to the water, more of which is forced through the moleskin. A die, also designed on the principle of reducing the side-friction, is made by Messrs. Clayton, Howlett and Venables.

The sides of the die are made up of large rollers, which are carried round by the issuing stream of clay. In some cases even, these rollers are rotated by power in the same direction as the clay travels, and rather faster, so the stream is actually helped to issue.

The Author has sometimes found a plain sheath-die answer very well. This consists of an internal and external case, with a space between; but fitted to one another, so that the front edge of the inner case fits closely to the outer, except up the vertical sides, and just round the corners where a slight opening is left. When the clay commences to issue, water is turned on to the annular space, and passing through only where there is an opening, lubricates the sides and corners only of the stream.

When very thin flat sheets of clay are required, say for roofing tiles, lubricating the ends is of no use. A good stream may be obtained by putting obstructions across the die in the centre, and so retarding its flow. These obstructions must be inserted some 2 or 3 inches back from the mouth of the die, so as to let the clay thoroughly unite again after passing them. Another way of putting more friction in the centre of a thin flat stream is to form the die-plate, say 4 inches thick in the centre, and taper it away to say 1½ inch at the sides.

Besides the semi-dry and plastic systems of brickmaking, another plan appears to be coming largely into use. This is a combination of the above two systems. The clay is prepared similarly to that for the semi-dry process, that is, it is reduced to fine particles in a perforated pan-mill. It has been attempted to reduce the clay to particles by passing it through rollers and a disintegrator; but the Author believes without arriving at any generally successful plan, owing to the difficulty of dividing the clay evenly and finely enough. After passing the mill the fine clay is taken to a small mixer and pug-mill, where it is mixed with just sufficient water to enable it to be forced in a plastic state into a die, and yet with so little that the bricks can be taken at once direct to the kilns, and stacked twenty or thirty high. Plate 2, Figs. 13 and 14 represent a machine of this class, as made by Messrs. Bradley and Craven of Wakefield. The clay is first discharged into the mixer, and a little water added, and is then carried forward to a small vertical pug-mill, from the bottom of which the clay is forced into a pair of dies, in a horizontal revolving table.

The table has an intermittent rotary motion, but it is stationary while the moulds are being filled under the pug. During this time another pair of bricks, which have been previously made, are

lifted out of the moulds at another part of the table, by self-acting mechanism raising the lower pistons of the moulds. These last bricks are then carried forward to be pressed in a separate press; the action of so doing pushes forward a pair of finished bricks, which have just been discharged from the press, and they are at once removed to the kiln. All these motions are self-acting, the clay not being touched by hand between the mixer and the press. Several somewhat similar machines are made in the Leeds district, but the above may be taken as a type of this class of machinery.

Drying Sheds.

Nearly all the best bricks and special goods are made from plastic clay, and are dried in sheds, not in hacks out in the open. In most cases these sheds are artificially warmed by heat applied under a hollow floor. This enables the work to go on in winter, when it would be impossible to dry the bricks out of doors. Sheds heated by ordinary fires are generally from 100 to 200 feet long, the fires being at one end.

In order to get an equal heat all along the sheds, the flues at the fire end are covered with earth some 12 inches thick, which is gradually reduced in thickness until it dies out to nothing about three-fourths of the length of the shed from the end where the fires are situated. It has become the custom of late years to utilize the exhaust-steam from the engines for heating the sheds. This is led under a hollow floor, usually covered with iron plates or stone flags.

Many clays will crack if laid on iron plates. Both these plates and stone flags are costly, and lead to a damp floor, as it is impossible to keep the moisture from coming through the joints. A hollow concrete floor, floated over with cement, has been tried at Otford by Mr. T. R. Crampton, M. Inst. C.E., but it appears difficult to prevent this cracking and letting the moisture through, owing to the expansion and contraction.

The Author, after having tried several plans, has found the hollow brick floors as used at Pluckley the best. By preference a site is chosen rising longitudinally, to allow the condensed water to drain away. A layer of 3 inches of concrete is spread all over the site. Flues measuring 6 inches wide by 4½ inches high, are formed along the floor by laying rows of bricks on edge 9 inches from centre to centre. The bricks are laid with open joints at the ends that steam may percolate freely everywhere under the floor. Paving bricks or tiles, 1½ inch to 2 inches

thick, are used to bridge over the flues. A bed of neat cement covers the whole, and on this is laid the final paving-course of hard bricks 2 inches thick. This forms a hard wearing surface, while the cement keeps the damp from rising, and does not appear to crack. The exhaust-steam is taken between the sheds in a main pipe, from which cross-branches controlled by throttle-valves are led, at intervals of about 40 feet. These branches have holes opposite each flue; should any section of the floor not be in use, the steam can be turned off. Live steam can be turned into these pipes when the engine is not at work.

The drying-sheds at Pluckley are used almost exclusively for making blue bricks. These are moulded as follows, viz., a stream of clay is forced out of a die, and cut by wires into rough blanks; these are taken to the drying-sheds, where, after a few hours, they become dry enough to be removed to the screw-presses, which finish them perfectly to any required shape. No dust or colouring matter is used in making the bricks.

In Staffordshire nearly all the blue bricks are hand-moulded, the clot of clay and the mould being dusted with a material, in which there is a considerable quantity of oxide of iron, to improve the colour. In some places it is the moulding dust alone which gives the blue colour. This is then only skin deep, whereas a good blue brick will be blue for $\frac{1}{4}$ inch in from the surface. Fireclay, or any clay which will stand heat sufficient to melt iron, can always be made into bricks with a blue face, by moulding it in dust containing iron or manganese.

KILNS.

At Pluckley four different types of kilns have been tried, the first, however, Mr. Bull's, being more for experimental purposes than for regular use. This kiln was erected to burn the bricks of which the works are built. It has simply two side walls, similar to a Scotch kiln, with side fires. The kiln is about 200 feet long, by 16 feet broad and 10 feet high, and is worked on the semi-continuous principle, that is, the fires are started at one end, and are gradually worked forward to the other end. The green bricks are stacked in a special manner, and are covered on the top with a layer of 6 inches of clay, in which are fixed small movable cast-iron feed-holes, through which dust-coal is fed to burn the bricks, the side fires being used merely to dry the bricks previously to firing them from the top. To get the draught at Pluckley, two portable sheet-iron chimneys were used,

carried on a small traveller spanning the side-walls of the kiln. The kiln was divided at intervals by sheet-iron dampers, stretching across to prevent back draughts, and also to keep the heat close to the bottom by only slightly lifting the dampers above the floor in the first instance. This kiln was badly built of green bricks, and its use was not persevered with after it was decided to erect a Hoffmann kiln. It burnt only 5 cwt. of coals per one thousand bricks. In India these kilns appear to have had considerable success, though there the system tried was somewhat simpler, the kilns being built on an incline longitudinally about 1 in 8, so that they required no chimneys or dampers to create or to regulate the draught.

Four Scotch kilns are shown on the general plan; these are used for burning plastic-made bricks dried under the hacks. They are simply of the ordinary type, and consume from 8 to 10 cwt. of coal per one thousand bricks burnt. Plate 2, Figs. 15 and 16 represent the plan and section of the kiln, as designed by Mr. Hoffmann. This was carried out, except that the external wall, enclosing the kiln in a building, was omitted, and the chimney was built in the centre of the kiln, instead of at the side; the latter was also built square instead of round as on plan. Plate 2, Figs. 17, 18 and 19 show the chimney in detail as built 170 feet high. The Author would direct attention to this system of chimney-building, which, though common enough in Germany, does not appear to be followed in England. It will be noticed that the brickwork is generally only 4½ inches thick, the walls being built of cellular work. Web-walls, 4½ inches thick, unite at intervals the inner and outer skins, each of which is also 4½ inches thick. The web-walls are joined together about every 10 feet vertically by rough arching or setting over the bricks. Ample stability is secured by allowing a good batter to the external skin, and also a large base. Since the walls are hollow the base can be built with but slight expense. This chimney, as compared with one built according to the usual English practice, has taken less than one-half the number of bricks. The Author attempted to build one of a similar design within the radius controlled by the Metropolitan Buildings Act, but it was not permitted. Another advantage of cellular chimneys appears to be that there is no cracking of brickwork; the inner skin is freer than usual to expand or to contract, while the air-space lessens the strain on the outer skin, and is a good non-conductor of heat. Cement is generally used to build these chimneys in Germany; but the one at Pluckley was built with exceptionally good lime mortar.

This kiln, though it has Mr. Hoffmann's latest improvements, is fired on the same principle as his first one, that is, it is fired continuously. It is fed about every twenty minutes with dust-coal through small holes covered with iron caps in the top. The air for the combustion is heated to a high degree beforehand, by passing through two or three chambers full of burnt bricks which require cooling, while all the products of combustion are passed through several chambers of unburnt bricks in various stages of burning and drying, until the products finally escape to the chimney with but little more than sufficient heat to cause the necessary draught.

The kiln is now built with fourteen chambers instead of twelve as was formerly the case, to allow of more time for drying the bricks. It is also built oblong with semi-circular ends in place of being perfectly circular, to save room and expense. Extra care is needed to prevent the fire cutting short round the ends. This is effected partly by setting the bricks closer at the inner part of the circular ends to check the draught, and partly also by feeding coal to a greater number of the outer circle of holes than of the inner ones. Each of the fourteen compartments must be provided with a damper to prevent the draught coming backwards. This is usually of sheet-iron, in several parts, placed across the whole section of the kiln, so that it can be withdrawn in pieces through the door just before the latter is closed. The dampers are always fixed opposite the door of each chamber. Sometimes a solid wall is built at the end of each chamber with four or five flues through it, each flue being covered with a small iron plate. These are withdrawn in the same manner as the above large dampers. Instead of iron dampers, Mr. Hoffmann used brown paper pasted all over the bricks across the kiln at the end of each chamber. This is the practice at Pluckley, and it is found to answer very well; even newspapers are sometimes used. The paper lasts long enough to keep all air-tight, and is ultimately destroyed either by the wet steam or the heat, when the nearest damper is raised in the flue leading to the chimney.

As the bricks to be burnt in the Hoffmann kiln at Pluckley are semi-dry ones, when they are put into the kiln they contain about 1 ton of water to each thousand bricks. This has to be driven out before they can be burnt. To assist the process, it was proposed to bring hot air from the chambers, where the bricks are cooling, past those chambers where they are being burnt, and on to those where they are being dried, by an underground flue and suitable dampers. In practice, however, it was found that the whole of the heat of

the cooling bricks could be taken off usefully by the current of air passing through to the combustion-chamber. The joints of all the dampers in the flues and feed-hole caps are made by the edge of the metal dipping into a trough of sand. Great care should be taken to lead all flues downwards until the top of the flue is below the level of the floor of the kiln; otherwise the great heat would ascend and destroy the metal. Valves in flues leading from the chambers in which bricks are actually burning are always kept shut. It is essential to have the floor of the kiln quite dry, and this is best secured by building the floor hollow. About one hundred thousand bricks per week can be burnt in this kiln at Pluckley, with a consumption of 4 cwt. or 5 cwt. of coal per one thousand bricks, which is a very moderate allowance when the amount of water to be dried out of the bricks is considered.

Many attempts have been made to improve the Hoffmann kiln. To save the trouble of loading and unloading the kiln, several different patterns of railway kilns have been used. The ruling principle of these railway kilns is to load the green bricks from the machine on to large railway trucks, each holding say 10 tons. These are gradually passed through a long kiln containing about fourteen trucks until they issue out at the far end. During their passage the bricks go through the various stages of drying, burning, and cooling according to their position in the kiln. The truck has no ends or sides, being simply an iron floor covered with firebrick, supported on four wheels. The floor of the truck is fitted with an iron lip on each side, pointing downwards, and running in a trough full of sand. The trough is formed by an angle-iron built into the side of the kiln, one flange of which stands some little distance from the side of the kiln and points upwards. This makes an air-tight joint between the truck and the kiln. A similar joint is made at the ends of the trucks between one truck and its neighbour. The bricks are piled on the trucks to the same section as the cross-section of the kiln with as little clearance space as possible. Iron doors, sliding vertically, are fitted at each end of the kiln, and are only moved to allow a fresh truck being pushed in at one end, and a finished one taken out at the other end, of the kiln. The wheels and axles are kept fairly cool by the current of cold air circulating underneath. Sometimes these kilns are fired from the side with large coal, and sometimes with dust-coal dropped through holes in the top, similarly to the Hoffmann kiln. It will be understood in the above case that the fires are stationary, and the trucks move. A great effort is necessary to move the trucks, as might be expected, on account of the hot and dirty state

of the bearings. To get over this difficulty, Mr. H. Dueberg, of Berlin, has adopted a modification, which consists in allowing the trucks to remain still from the time they are put in the kiln until they are taken out, while the fire moves around continuously as in a Hoffmann kiln. This requires the kiln to be either square or oblong on plan.

Hoffmann kilns have been modified to use gas. None of them, however, have been built in England, though many have been put up in Germany and in France, and appear to give satisfaction. Gas is formed in any ordinary generator, and is introduced, from below the floor, through vertical perforated fire-brick pipes. All gas-flues are controlled by valves. By means of a flue running along the top of the kiln and movable iron tubes, any two or more chambers can be put in connection with one another, and thus waste heat can be passed from any of the chambers which are cooling to those in which the bricks are being dried and warmed.

The Hoffmann kiln has effected a great change in brick manufacture owing to its burning thoroughly good sound bricks with less than half the fuel before used, yet it is difficult to get any of the higher class of facing bricks burnt in it, as the colour of the brick is generally inferior. It is said that the use of gaseous-fuel overcomes this defect to a large extent. It can hardly do so entirely if the cause of the bad colour be (as is generally understood) the bringing cold air into contact with the hot bricks, after they are burnt, and so cooling them too rapidly.

In the Appendix, Table I. gives the cost of making bricks in the Sittingbourne district and also in the Cowley and Southall district. The bricks are moulded by hand, but the clay is prepared and pugged by machinery. Table II. gives the cost for a whole year of brickmaking per one thousand machine-bricks made at a large works in Yorkshire. The bricks were wire-cut, and were dried under heated sheds in the winter, but under hacks in the open in the summer.

The cost of making semi-dry bricks is somewhat less than the cost of making plastic bricks, but the wear-and-tear and depreciation of machinery are greater. The cost of labour only in making semi-dry bricks is from 7*s.* to 8*s.* per one thousand. Table III. gives the crushing strength of some blue bricks, some semi-dry ones made of slate debris, also of some red plastic bricks.

The Paper is accompanied by numerous drawings, from which Plates 1 and 2 have been engraved.

[APPENDIX.

APPENDIX.

TABLE I.—COST of BRICKMAKING in the SITTINGBOURNE and also in the COWLEY and SOUTHALL DISTRICTS, per 1,000 BRICKS MADE.

The clay was prepared by machinery; the bricks were moulded by hand and burnt in clamps, according to the usual London practice.

	Per 1,000 Bricks. Sittingbourne.		Per 1,000 Bricks. Cowley and Southall.		
	s.	d.	£.	s.	d.
Washing and wheeling earth	1	6	0	1	4
Ashes and breeze and wheeling on	2	6	0	2	9
Chalk	0	9	0	1	6
Moulding	4	6	0	4	10
Setting	2	0	0	2	1
Skintling	0	3	0	0	3
Engine, &c., pugging, including fuel and stores	1	0	0	0	9
Sand	0	6	0	0	9
Sorting	0	9	0	1	0
Waste	1	0	0	0	9
Wear and tear, tools and plant, including hack caps and boards	1	6	0	1	3
Foreman	0	6	0	0	7
Rent, rates and taxes	0	6	0	0	6
Royalty	2	0	0	2	0
Total	19	3	1	0	4

TABLE II.—COST of MAKING PLASTIC BRICKS per 1,000 for ONE YEAR in YORKSHIRE.

	Per 1,000 Bricks. Summer, April to September.		Per 1,000 Bricks. Winter, October to March.		
	s.	d.	£.	s.	d.
Wages	9	9¾	0	10	3¾
Oil and grease	1	4¼	0	1	8¾
Coals	2	3	0	4	7
Rates and taxes	0	1	0	0	1
Repairs	0	6	0	0	8
Land (freehold)	1	5½	0	1	6
Interest	1	2	0	1	4¼
Depreciation	0	9	0	0	9
Average each half year	17	4½	1	0	11¾

These bricks were dried in the open air during the summer, but in drying-sheds heated by fires in the winter.

TABLE II. (*continued*)—DETAIL of COAL USED per 1,000 BRICKS.

	Cwt.
In Hoffmann kiln per 1,000 bricks burnt	3
„ drying shed „ „ dried	4¾

COST per TON of COALS on SITE.	Per Ton. s.	d.
Engine coals	16	0
Slack for drying shed	6	6
„ kiln	6	10

TABLE III.—RESULTS of EXPERIMENTS to ASCERTAIN the RESISTANCE to a GRADUALLY INCREASING THRUSTING STRESS on VARIOUS BRICKS.

SIX BLUE BRICKS MADE by J. HAMBLET, WEST BROMWICH.

Dimensions.	Base Area.	Stress in lbs. when		
		Cracked slightly.	Cracked generally.	Crushed, Steelyard dropped.
Inches. 2·74–9·03×4·36	Inches. 39·24	378,600	532,000	689,220
„	„	355,200	521,800	678,890
„	„	339,100	483,000	668,310
„	„	319,400	411,550	636,180
„	„	311,500	404,600	624,250
„	„	306,800	402,000	603,420
Mean		335,100	459,158	650,045
Lbs. per square inch . .		8,531	11,689	16,549
Tons per square foot . .		548·6	751·7	1064·2

TABLE III. (*continued*)—SIX BLUE BRICKS MADE by WOOD and IVERY, WEST BROMWICH.

Dimensions.	Base Area.	Stress in lbs. when		
		Cracked slightly.	Cracked generally.	Crushed, Steelyard dropped.
Inches. 2·80–8·75×4·12	Inches. 36·05	168,000	281,000	387,520
„	„	155,000	264,000	382,110
„	„	149,000	258,000	378,230
„	„	144,000	236,000	366,210
„	„	133,000	223,000	347,540
„	„	128,000	211,000	328,620
Mean		146,166	245,500	365,038
Lbs. per square inch . .		4,054	6,809	10,125
Tons per square foot . .		260·7	457·8	651·0

TABLE III. (*continued*)—SIX WHITE GLAZED TERRA METALLIC BRICKS MADE by WOOD and IVERY, WEST BROMWICH. (Recessed both sides.)

Dimensions.	Base Area.	Stress in lbs. when		
		Cracked slightly.	Cracked generally.	Crushed, Steelyard dropped.
Inches.	Inches.			
3·10–8·80×4·22	37·14	156,240	168,300	173,460
3·15–8·65×4·20	36·33	141,800	162,140	166,380
3·12–8·80×4·25	37·40	137,500	158,400	164,220
3·16–8·65×4·28	37·02	129,770	148,650	155,340
3·18–8·76×4·37	38·28	113,840	147,200	152,710
3·16–8·70×4·34	37·76	104,120	133,900	140,880
Mean		130,545	153,098	158,832
Lbs. per square inch . .		3,498	4,102	4,256
Tons per square foot . .		225·0	263·7	273·7

TABLE III. (*continued*)—SIX BRICKS MADE of SLATE DEBRIS by the SEMI-DRY PROCESS by J. OWEN, GLOGUE, WHITLAND, SOUTH WALES.

Dimensions.	Base Area.	Stress in lbs. when		
		Cracked slightly.	Cracked generally.	Crushed, Steelyard dropped.
Inches.	Inches.			
2·33–8·70×4·25	36·98	355,200	504,000	633,180
”	”	339,500	495,000	618,240
”	”	322,800	488,400	614,770
”	”	309,200	471,000	607,810
”	”	298,000	459,200	588,260
”	”	295,200	452,500	581,920
Mean		319,983	478,350	607,363
Lbs. per square inch . .		8,653	12,935	16,424
Tons per square foot . .		556·4	831·8	1,056·2

TABLE III. (*continued*)—FIVE RED BRICKS MADE by THE ADDERLEY PARK BRICK COMPANY, SALTLEY, BIRMINGHAM. (Recessed one side.)

Dimensions.	Base Area.	Stress in lbs. when Cracked slightly.	Cracked generally.	Crushed, Steelyard dropped.
Inches.	Inches.			
3·20–8·90×4·35	38·71	79,990	112,760	122,040
3·25–9·00×4·40	39·60	97,150	113,600	119,450
3·25–8·95×4·35	38·93	93,640	107,720	118,460
3·20–9·00×4·40	39·60	84,200	104,250	106,400
3·25–8·95×4·40	39·38	68,400	82,740	84,560
Mean		84,676	104,214	110,182
Lbs. per square inch . .		2,157	2,655	2,808
Tons per square foot . .		138·7	170·7	180·5

All the bricks were bedded between pieces of pine ⅜ inch thick; recesses filled with Portland cement.

TABLE IV.—RESULTS OF EXPERIMENTS TO ASCERTAIN THE RESISTANCE TO A GRADUALLY INCREASED THRUSTING-STRESS OF SIX BRICKS, MADE BY CRAVEN'S PATENT BRICKMAKING MACHINES. (Red brick, recessed both sides, "Craven" in recess.)

Dimensions.	Base Area.	Stress in lbs. when Cracked slightly.	Cracked generally.	Crushed. Steelyard dropped.
Inches.	Square Inches.			
2·90–8·75×4·24	37·10	236,300	288,600	328,860
2·95–8·80×4·28	37·66	224,400	281,000	306,920
2·90–8·70×4·20	36·54	201,900	258,000	300,780
2·90–8·75×4·24	37·10	197,000	235,000	271,230
2·90–8·70×4·20	36·54	184,200	227,900	266,310
2·90–8·65×4·15	35·90	172,800	212,400	230,160
Mean . .	36·80	202,766	250,483	284,043
Lbs. per square inch . .		5,509	6,806	7,718
Tons per square foot . .		354·2	437·6	496·3

Bedded between pieces of pine ⅜ inch thick. Recesses filled with cement.

[DISCUSSION.

Discussion.

Sir Frederick Bramwell, President, said the Paper dealt with a manufacture, the product of which entered more into English engineering construction than did any other material, and it was one which, even where stone was cheap, had the great advantage of being shaped ready to hand, and being, when thoroughly well made, trustworthy for all time. Sir F. Bramwell.

Mr. Henry Ward called attention to the samples of bricks on the table, and tracings of the chain-gear. The latter, he said, represented a mortar-mill with the pan removed, and chain-wheels, about 5 feet in diameter, substituted, so that the chains could be led to any position without guide-rollers, having simply supporting rollers at intervals. The Tables showing the cost of brickmaking had been compiled from the actual cost-sheets. The makers of brickmaking machinery, he was afraid, would say that the cost was too high, but he thought that, as a rule, they did not take into account all the considerations which ought to be borne in mind by those who had to make bricks for profit. Among other items were the interest on capital, the value of freehold land, the renewal of plant, and the sinking fund, which nearly all brick-fields had to allow to repay the capital when the lease expired. With reference to a statement in the Paper that the pistons of some dry brick-machines were kept hot by steam, he believed that in a few instances the moulds, not the pistons, were kept hot in that way. Practically, that was very much the same thing, seeing that the pistons were in constant contact with the moulds, and so became hot. A film of vapour formed on the pistons, which made a lubricating material, and enabled the brick to be easily discharged. Mr. Ward.

Mr. W. H. Venables said he preferred the plastic process, because of the frequent failure of the semi-dry process, the bricks yielded on the face, and did not stand the weather so well as those produced by the plastic process. Plastic bricks were made with much greater facility than semi-dry bricks. The majority of clays were found wet, and were easily treated as such; but by the dry process they had to be partially dried before they could be treated. As the Author had stated, the semi-plastic process was certainly coming into vogue, and almost every brickmaker was endeavouring to use it. In this process also, however, there was the difficulty of the clay not being in a fit condition to be treated immediately. Mr. Venables.

Mr. Monson. Mr. E. Monson had been disappointed to find that the Paper was not entirely devoted to brickmaking. The first part appeared to deal with the stock brickmaking process. No doubt in the neighbourhood of London that system in the past was the best that could be adopted; but at the present time it was nearly going out, and brickmakers wanted to know what they were to do under the circumstances. For stock brickmaking they required wash-mills, breeze, and so on, but those things would not be needed for other processes. Very little description had been given of the machinery employed. He was of opinion that the semi-dry process was that which would be used henceforth in the neighbourhood of London, because nearly all the brick-earth had been worked out; there was none in the north, very little in the south, and in the west it was nearly all exhausted up to the neighbourhood of Windsor. The question, therefore, was how to deal with the London clay. For the semi-dry process it would have to go into a 9-feet perforated pan, and pass through it. The difficulty was that the material as it came from the clay-pit was too wet to pass through the perforations. But that could be got over by drying the clay and by putting in dry materials, such as soft bricks, burnt ballast or clinkers. The process was easy enough. The clay went from the perforated pan into the mixer, next into the machine; then it came out a moulded pressed brick, but it was usually pressed again. He did not think that putting the bricks directly into the kiln would be a good plan, because they would probably fly, not being sufficiently dry; and besides this the steam from the lower bricks would spoil those that were above. Generally it was necessary to put them on drying-floors. The Hoffmann kiln appeared to be a good one, but he was told by practical men that there was no gain, in regard to cost, by that method of burning. If it could be kept regularly at work, burning, say, one hundred thousand bricks per week, it might perhaps be worked with advantage; but to ensure this it was necessary that all the orders should come in in the same regular way. By the old process a field was skimmed 4 feet or 5 feet deep to obtain the brick-earth, which had a good deal of sand in it, so that the bricks dried without cracking. On account of its being deficient in sand the London clay must be worked much drier, so that the semi-dry or the semi-plastic process was needed. In working the London clay, by either of these processes, the machinery was fixed, and it was possible to go to a great depth to get the clay out; but where the field was skimmed the machinery had to be constantly moved about. He considered that the list of machines mentioned

in the Paper was imperfect, many that were in the market not being represented. Mr. Monson.

Mr. F. Howlett said the chief difficulty brick-machine makers had to contend with was the great variety in the material to be dealt with. There were the strong London clay, the very sandy clays, the tough leathery blue gault, the hard Staffordshire marls, the shales, which were almost like pieces of rock, and the various fire-clays. They were expected to deal with all kinds of material, and it was no wonder, therefore, that brick-machines were not always as successful as might be desired. He had placed on the table a box of samples of ninety different kinds of clay, all of which had been selected and used for brickmaking purposes, and many more might have been sent. Feeding brick-machines regularly was, no doubt, an important point, especially in the case of plastic-clay machines, for if the clay was not properly put into the hopper, it could not come out at the other end in the form of bricks. That matter was very often overlooked in the brick-yard. Brick-machine makers were often required to explain why a particular machine did not make as many bricks as it ought to do; but on inquiry it generally turned out that the clay had not been constantly put in. When that was insisted upon, the machine made 50 or 100 per cent. more bricks than before. The plan of feeding by small trucks was advisable, because the clay was then thoroughly well mixed. The system of drawing by chain was no doubt very good, but on the steep inclines generally used, often of 1 in 2 or 3, he doubted whether the chains would hold tightly enough. Reference had been made in the Paper to dies, which were lined inside with metal plates, laid over one another like scales, and with water passing between the scales at the corners of the dies. That answered very well in many cases, but he had sometimes found that water would not answer, but oil would, and in several instances, where neither water nor oil were successful, steam had overcome the difficulty. The Author had stated that in Staffordshire the blue bricks were nearly all made by hand. Mr. Howlett thought that many blue bricks were now made by machine. In one case his firm had put up machinery sufficient to make fifty thousand bricks per day, and he knew of several other works in the same neighbourhood where a large number of blue bricks were made by machine. The Author had also said that good blue bricks should be coloured ¼ inch in from the surface. Mr. Howlett should not call a brick blue for only ¼ inch a good blue brick. The best bricks were coloured blue nearly or quite through. He had that afternoon broken a blue Mr. Howlett.

Mr. Howlett. brick made by the Cakemore Brick Company at Rowley Regis, and it was blue quite through.

Mr. Barry. Mr. J. W. Barry was sure the importance of brickmaking to engineers would be admitted, especially where stone was difficult and costly to procure. In London they had had the great advantage of their predecessors pointing out the value of the London stock-brick, which experience had shown to be as good for engineering purposes as almost any bricks in any part of the world. In the stock-brick the ashes were mixed with the clay; the whole brick was thus burned together and completely indurated by one process of firing; whereas other kinds of bricks were burned by external heat applied to them after they had passed through some drying process, and they were consequently much more dependent than stock-bricks upon skill in drying and firing. What engineers wanted brickmakers to do for them was to produce a brick which would bear a high compressive-strain in proportion to its weight, and in connection with other qualities. He protested against the practice which had been growing of late years of mixing a large quantity of chalk in the preparation of stock-bricks. The plastic clay overlying the London clay would bear a certain proportion of chalk, but unless great attention was given to the mixture a weak brick was produced, which would not stand compression or the effect of weather as the old stock-bricks made fifty years ago did. He regretted that no details had been given of the strength of bricks in proportion to their weight. If such details could be added they would, he thought, be very valuable, because weight was a matter of very great consequence to engineers. Weight over and above that which was necessary to produce a given amount of compressive strength involved waste, not only in labour (because every brick had to be handled and placed in position by workmen), but also waste in carriage, and unnecessary cost in the means of supporting structures, whether by the use of girders and arches such as were so frequently required in large towns, or by unnecessarily large foundations. The best brick for the smallest amount of weight should be sought for. He was not sure that weight was necessarily an index of compressive strength. He had had heavy bricks made by the dry-process, which had not stood a high compressive strain, but had shown a tendency to give way and fall to pieces. With regard to the large frog in the brick, he was much against such deep depressions, which could not add to the strength of the brick, but might add very much to its weakness, besides being the receptacle of a large and wasteful amount of mortar, which was objectionable

in many ways. Mortar was more costly than the material of the brick itself, and if the cavities were properly filled the brickwork when built took a long time to dry; on the other hand, if not properly filled, the brickwork was unsound. A small depression in bricks was no doubt advantageous in giving a key to the mortar, but it ought not to be much greater than that used in the old London stock-bricks. In the next place engineers wanted a brick that gave a suitable surface for securing adherence to the mortar and cement used in putting the brickwork together. They might have a very sound brick, but it would not make sound work unless it had such a surface as would enable the mortar to adhere to it properly, and thoroughly unite all the brickwork. These matters to which he had alluded might appear small, but they were really of very great importance. When it was remembered that for 1 yard of brickwork about three hundred and fifty bricks had to be united by the skill of the bricklayer, and that the cost of the mortar required to unite them had to be taken into account, it would be seen that all such matters of detail were of consequence, and should be attended to by any brickmaker who wished to suit the requirements of the engineer as much as possible. Mr. Barry.

Mr. E. A. Cowper had noticed for many years, with great interest, the gradual improvements in brickmaking machines. He remembered the first application, fifty years ago, of the mole-skin round the main rollers, to prevent the clay from sticking, as introduced by the Marquis of Tweeddale, also a machine by the late Mr. John Hague, which had a flat, circular revolving table with moulds. The clay was intended to be pushed into the moulds, but it did not fill the moulds. It was not known at that time how the mould could be well filled with clay in a proper condition. The imitation of what brickmakers did by hand, namely, smashing the clay in, and shoving it down in the corners, was not very simply accomplished by a machine. In the first place the clay was in a very moist condition, with the express view of lightening the labours of the brickmaker, but there was a great advantage in the handling and drying after the making, if it was in a stiffer condition, and therefore machines were made accordingly, to use the clay somewhat stiffer. In many machines there was a difficulty in filling the extreme corners under sufficient pressure, and the reason was a simple one; the clay experienced much friction against the sides, ends and bottom of the mould, and being semi-fluid it formed, so to speak, a kind of quarter dome in the extreme corners, and this had to be Mr. Cowper.

Mr. Cowper. squeezed down by extreme force so as to form sound corners in the mould. Of late years, however, it had been usual to avoid such great resistances by simply pressing a stream of clay of the section of a brick through a die by means of rollers, when the angles of such stream only had to be brought up sharp by pressure, there being no corners to be filled; then when the solid stream was cut clean off by wires (as now practised), the corners of such bricks were as sound as any other part. The efficient way in which the clay was forced forward through the die, by means of two rollers placed near together, depended of course on the powerful hold that they had on the thin stream of clay carried forward between them, which was sufficient to fill almost any die. Of late, the clay been much better prepared, especially some of the hard clays such as gault, and others of that description. It required to be much broken up, and separated, so that almost every particle might be pulled away from its neighbour, a proper quantity of water being introduced to bring the whole into a plastic condition; otherwise it was lumpy. Every particle required to be wetted before it was brought into a homogeneous state; that was partly done in some machines by cutting up, or crushing with rollers. He thought that Mr. T. R. Crampton had been successful, first in cutting the clay by rollers, making about two hundred revolutions a minute, and then in crushing it through rollers and mixing it with chalk and water. Drying on floors was, of course, a modern invention, and was sometimes done by the steam being turned underneath the floors in flues, steam-pipes not being needed. He had seen several Hoffmann kilns, and had observed one fault about them; they burnt the clay admirably, but many of the bricks had marks upon them, as though the colour had been stopped from developing by other bricks with which they had been in contact. That was owing to the fact that the air was brought upon the bricks while they were at a red-heat, so that any iron that was in the clay in those parts exposed to the air became oxidized and red. Where the air could not get freely to the bricks, they were not so oxidized and coloured. The result was that the bricks had bands and marks across them. That, however, was simply a fault in appearance; and in the case of a garden-wall it looked rather picturesque than otherwise. The bricks were none the worse in quality. Fire-bricks were now sometimes burnt in the long kiln like a lear described in the Paper. The bricks went in at one end, got gradually warm, then thoroughly hot, and then passed out and gradually cooled, the draught of air being in the opposite direction to that of the bricks.

Mr. Robottom. Mr. ARTHUR ROBOTTOM exhibited specimens of bricks glazed with boracic acid, and made from clay found in the neighbourhood of Ongar. Boracic acid, he said, which was formerly sold at £140 per ton, could now be obtained for £23, and glazed bricks, therefore, ought to be sold (according to the Author's Tables), at 70 or 80 per cent. less than their present price. Such bricks were extremely useful in passages and kitchens. Boracic acid was found in Italy. The vapour was forced up from the interior to the surface of the earth, coming into a kind of artificial lake; the water was run off into tubs, and the crystals that formed were boracic acid.

Mr. Bromfield. Mr. J. COLEY-BROMFIELD said he was connected with a company that had introduced a brick made from slate débris, millions of tons of which disfigured the landscape in North and in South Wales. It had been stated that London clay was all worked out: here was a clay in a concentrated form, which only required the use of special machinery to convert it into bricks unsurpassed for compactness, durability and strength, and peculiarly adapted for engineering purposes, at a cost about one-third less than ordinary hard red bricks. The shale or waste slate was powdered to very small particles by machinery supplied by Messrs. Whitaker. It then descended through perforated plates into a pit, from which it was lifted by elevators to a stage above, and there forced through a mixing-trough, where a small quantity of water was added. It then passed through another trough into the hopper of the brickmaking machine, and when moulded it was carried straight into the kiln without any previous drying, and there stacked at once; the pressure was so great that nearly all moisture was forced out; so that a kiln could be fired on the very day when the last lot of bricks was put in. The bricks, he believed, were the strongest ever made in the country, the crushing-strain being equal to 1,056 tons per square foot, some not breaking even at that. He also wished to direct attention to a firestone-brick, in which a wrought-iron bolt had been put when the brick itself was burning, to ascertain what heat it would stand. The brick, it would be seen, was perfect; but the iron bolt had been melted into it. He believed that those bricks would stand the strongest heat ever required for steel furnaces, and several works had been supplied with them. Some of the slate bricks had been sent to London and sold for the foundations of a church at Rotherhithe. The company's present works was the only establishment of the kind; but licenses had been given for others in different parts of the country. Amongst its customers were

Mr. Bromfield. the Great Western, the London and North Western, the Mid-Wales, and the Cardigan and Whitland Railways. At the International Inventions Exhibition the company's brick was the only one that gained a medal.

Mr. Giles. Mr. A. GILES, M.P., had been somewhat disappointed with the figures given by the Author as to the cost of brickmaking by machinery, as they appeared to show very little saving in labour as compared with the old hand-process. It would seem from the figures that the cost of labour employed in making bricks by hand was about 9*s.* 6*d.*, as against 9*s.* 9¾*d.* for one thousand. It was well known that there were bricks and bricks. When a contractor bought a thousand bricks, he wanted first to know their size, because a brick might be very good, but it might be of such a size as to make 15 or 20 per cent. difference in a cubic yard of brickwork. There had been a wonderful development of the brick-trade since the duty had been taken off. He remembered buying a large quantity of bricks when 5*s.* a thousand was paid for duty, and the whole cost was only 28*s.*, including the duty and cartage to a distance of 3 miles. Seeing that machine-made bricks now cost 17*s.* 4*d.*, and hand-made bricks 19*s.* 3*d.* per thousand in the brick-yard, there did not appear to be much reduction in price since the time to which he alluded. Considering the perfection which machinery had attained, he thought the price ought to be cheaper. There was certainly an advantage in making bricks by machinery, as brickmakers were by no means the most desirable set of men to deal with. They were hard-working and hard-drinking men, given to strikes, and very difficult to manage. Their task was certainly most laborious. One man at a stool would make from eight thousand to nine thousand bricks in a day, and for that purpose he would have to turn out ten bricks every minute from the mould during fifteen hours. Considering the exhaustion produced by such work, it was no wonder that the men were occasionally unruly.

Mr. Ward. Mr. H. WARD, in reply, said it was no doubt advisable to have a light brick for many purposes; but for some purposes, such as foundations and retaining-walls, it was better to have a heavy one. Of course, where stress was put on foundations, as in the case of chimney-building, it was important to have as light a brick as possible. Mr. Venables had remarked that it was necessary to dry clay artificially before it was used in a semi-dry brick-machine, or passed through a pan. That was not so. He knew of only two works in the country where that system was used. He believed it had been employed for a time at Mapperly, in Notting-

hamshire, where some clay which was too plastic to be ground through a perforated pan-mill, was partly dried on a steam-heated floor on its road to the machine-house. At Pluckley, during the winter, it was constantly found that the clay was too plastic to go through the pan, but there was a very ready mode of getting over the difficulty, namely, by mixing a little burnt ballast, or even ashes in some cases, with the clay. The Hoffmann kiln needed no defence from him. It had certainly reduced the consumption of coal to something like one-fourth, or one-third what it was formerly. It had burned bricks with 2 or 3 cwt. of coal per thousand, whereas the Scotch kiln used to burn 8 or 10 cwt. True, the colour was not the best, as had been stated, but the bricks were first-rate for engineering purposes. It had been said that during the last two or three years the difficulty had been overcome to a large extent by the use of gas as fuel, but he was a little doubtful on that point. The difficulty arose, he believed, as Mr. Cowper had explained, by bringing the air in contact with red-hot bricks, which no doubt had a great oxidizing influence. In other kilns, where it was important to have a good colour, it was the custom directly the bricks were burnt to close up every inlet to the kiln through which air might come, so that the cooling process often took three or four days; whereas in the Hoffmann kiln the cooling was very rapid. As to the size of the brick, he thought that bricks should be bought by the cubic yard rather than by the thousand, so that contractors would know exactly what they were buying. Bricks in Scotland were made with the joint 4 inches thick; in Yorkshire with the joint $3\frac{3}{8}$ inches; in Birmingham about the same; towards the south they varied from 3 inches with the joint to 3 inches without it. Those who bought bricks should be careful in getting the exact size, or a guaranteed measure per thousand. As to blue bricks being coloured right through, he believed that was the rarest thing possible, and the reason was not difficult to comprehend. That which gave the colour to the bricks was practically the melted oxide of iron, and it was impossible to get the heat inside the brick without overburning the outside. At any rate very few clays would stand that heat. If a brick was blue a $\frac{1}{4}$ inch in, it was a thoroughly good brick. If a brick was blue right through it would generally be found that the outside was more like a cinder, having had all the substance burnt out of it; it would be twisted and distorted, and probably cracked through. It would be news to Londoners to hear that stock-brickmaking was going out. Machine-makers had been trying to introduce machinery for plastic clay in the Mr. Ward.

Mr. Ward. London and southern districts for many years, but practically with very little success. Stock-brickmaking still held its own, and he believed would continue to do so. Its advantages were very great, especially in the neighbourhood of large towns; the chief advantage being that practically no fuel, ordinarily so called, was used. House ashes could be had for nothing, and even for less than nothing, for he had known a case in which 3*d.* a cart-load was paid for permission to deposit them on a field. While that was the case it was very doubtful whether any kiln-bricks would supersede the London stock-bricks, at any rate in the southern districts. With the stock-brickmaking process it was possible to use clays that could not be employed by any other process—clays so rich that it would be very difficult to make them by a machine for plastic clay, or in any other way, because they would be cracked and distorted in all directions; some of them being so sandy that persons not accustomed to them might think it impossible to use them at all for bricks. The result was accomplished by the mixture of chalk and other substances with the clay. In accordance with the suggestion of Mr. J. Wolfe Barry, he submitted the following particulars of the weight per 1,000 of different bricks that had been tested. As the bricks varied in size, it had been necessary to calculate the weight of the bricks for the standard size of $8\frac{3}{4}$ inches by $4\frac{1}{4}$ inches by $2\frac{5}{8}$ inches from the actual weight, otherwise a fair comparison of their weights and strengths could not be made.

Bricks made by	Approx. weight per 1000. Cwt.
J. Hamblet	68
Wood and Ivery	70
J. Owen	56
The Adderley Park Brick Co.	56
Bradley and Craven	77

The weight of London-made stock-bricks, of the above size, was about 48 cwt. per 1,000.

Correspondence.

Mr. Hill. Mr. J. W. Hill observed that the method of making bricks by hand was too well known to need notice, except as to the extraordinary tenacity of life exhibited by this ancient process. On the other hand, bricks produced by the semi-dry process had not stood the test of time nearly so well as their ancient compeers, the mode of their manufacture inducing disintegration in a compara-

tively short time; semi-dry bricks were also porous and absorbed moisture, causing damp walls and percolation. The direction in which machinists of the present day were progressing, was that of the semi-plastic process, the happy medium between the hand-made and the semi-dry processes. The Author had not mentioned the brickmaking machine with double screws; this had the great advantage over the single-screw machine of performing twice or thrice the work on the clay in a given time. The body of the former machine was considerably shortened, and the clay rendered more thoroughly homogeneous than by the single-screw machine. Nearly every brick-maker had his own pet form of brick-die, but one of the simplest and most effective was a plain parallel water-die made of soft wood, with a depth of about 9 inches from back to front, and lined with fustian in one piece, tacked round the back of the die and left perfectly loose towards the front of the die. A groove was cut round the wood-work inside, about ½ inch wide and ⅜ inch deep, to allow the water to flow from the water-can all round the die between the wood and the fustian. By leaving the fustian loose, as above described, it was always perfectly smooth, and did not form creases as it did when the fustian was secured, nor did it wear out so fast. The pressure of the clay on the fustian prevented the water escaping too rapidly from the die. In all methods of brickmaking, the utmost attention should be given to the proper digging, weathering, watering, and pugging of the clay. The action of weather and water performed many most important functions, which could not be exactly imitated, nor the same effects produced, by machinery; and even where this work was attempted by machinery, it was performed at a cost of plant and wear-and-tear far in excess of the natural processes of weathering and watering. Many intractable clays became amenable to treatment by machinery if allowed to soak with water or steam for a few days. With many clays, bricks could be produced by a double-screw machine with the fustian die at 12*s.* per thousand, including all expenses except rent, royalty, and first cost of plant. Mr. Hill.

Mr. A. W. Itter remarked that, in manufacturing semi-dry bricks, a great improvement was effected by having a revolving screen placed on the floor above the machine, so that the elevators might deliver the clay from the perforated pan direct into the screen. The finer particles of clay which fell through the screen were used in the ordinary manner to make bricks; while the coarser particles which passed out at the end of the screen, were returned to the clay-pan to be re-ground. The output of the Mr. Itter.

Mr. Itter. machinery was increased as larger perforations were used in the clay-pan, and the quality was better than where no screen was used, as the particles were more uniform.

Mr. Wedekind. Mr. HERMANN WEDEKIND stated that he had been for many years closely connected with Mr. Hoffmann and the kiln bearing his name. He differed from the Author as to the cause of the so-called bad colour of bricks. The attempts in England to exclude the air after burning, by building permanent brick walls at the end of each compartment, leaving only sufficient openings at the bottom to allow the air needful for combustion to pass along the floor, did not cure the evil complained of. In Germany, on the other hand, where the bricks were generally stacked drier, and heated and afterwards cooled more gradually, a very good colour was obtained. Besides, the gas-kiln referred to by the Author worked exactly on the same principle as the Hoffmann, except that for fuel a large number of gas-jets was substituted for the small coal. In his opinion, the discoloration of the bricks was caused solely by the steam discharged from them while heated, producing with the carbonic acid of the fuel a chemical action, which showed itself even after burning by discoloration, or by forming a kind of scale. With regard to machinery for semi-plastic bricks, English engineers had taken the lead for many years. Amongst others, Messrs. Bradley and Craven, of Wakefield, had supplied their machines to the collieries with marked success, especially in Germany, utilizing the shale as raised to the pit's mouth.

4 May, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate has been transferred to the class of

Members.

George Hodson.

The following Candidates have been admitted as

Students.

Joseph Edward Davies.
David Morgan Jenkins.
James Newsome Matthews.
Walter Bishop Purser.
Arthur Henry Wakeford.

The following Candidates were balloted for and duly elected as

Members.

Joseph Hobson.
James Young.

Associate Members.

Arthur Beckwith, Stud. Inst. C.E.
Philip George Brunton.
George Murray Campbell.
Charles Dick.
John Gill.
Edward Rainford Jackson, Stud. Inst. C.E.
John Arthur Dayrell Lloyd.
Richard Loch.
James Meldrum.
Carl Emil Nabholz.
Robert Robertson, B. Sc., Stud. Inst. C.E.
Alexander Charles Schönberg.
William Charles Ernest Smith.
James Thropp.
John Alexander Warren, Stud. Inst. C.E.

Associate.

George John Armytage.

(*Paper No. 2165.*)

"The Mersey Railway."[1]

By FRANCIS FOX (of Westminster), M. Inst. C.E.

THE Mersey Railway Company was incorporated by Act of Parliament in the year 1866, with the object of effecting a junction between the railway systems on each side of the River Mersey, and therefore between the city of Liverpool and the town of Birkenhead, situated on the Lancashire and Cheshire shores of the Estuary.

The authorized railways of the Company represent a total length of 5¼ miles of double line, on the standard gauge of 4 feet 8½ inches. The main line passes under the River Mersey near the Woodside ferry, and forms a junction at Birkenhead with the London and North-Western and Great Western joint railway from Chester. It will also be connected with the Wirral Railway, Hoylake, New Brighton, the Dee Bridge, Chester and North Wales; with the Dock lines on both sides of the river, and with the Central Station, Liverpool. The portion completed, and forming the subject of this Paper, extends from a junction at Union Street, with the Joint Railways of the London and North-Western, and Great Western Railway Companies, under the Estuary of the River Mersey, to Church Street, Liverpool, a total length of about 3 miles.

The works were begun in December, 1879, when a preliminary contract was entered into with Major Isaac, who undertook the risk of driving an experimental heading under the River Mersey. Borings taken with Sir John Hawkshaw's machine had shown that the New Red Sandstone rock extended generally across the river, but it was felt that nothing short of an actual heading could demonstrate the continuity of the rock, and its freedom from fissures.

It was not, however, until May, 1881, that this preliminary work had advanced to such an extent as to justify the commencement of the permanent works. The necessary contract having been made, the main works were proceeded with in August, 1881, and having been vigorously prosecuted by day and by night, were opened by H.R.H. the Prince of Wales, on the 20th of January, 1886, public traffic commencing on the 1st of February, 1886, a little over six years from the starting of the preliminary works.

[1] The discussion upon this Paper was taken together with that upon the following one.

Owing to the main tunnel being on a falling gradient towards the river (Plate 3), the difficulty of keeping the working face free from water would have been very great. It was therefore proposed that shafts should be sunk at Birkenhead and Liverpool, to such a depth that a special drainage-heading could be driven with a slightly rising gradient, so as to meet the main tunnel under the centre of the river, and this suggestion has been carried into effect. The water thus gravitates to the bottom of the shafts, from whence it is pumped to the surface. It was also decided that the pumping machinery should be placed at the top of the shafts, and not underground, so as to avoid any chance of the pumps being drowned.

Drainage-Heading and Pumping-Machinery.

The works were commenced by sinking two shafts (Plate 4), one at Liverpool, 15 feet in diameter, and about 170 feet in depth, to the bottom of the sump; and one at Birkenhead, 17 feet 6 inches in diameter, and of similar depth. The distance between the quay-walls on the two banks of the Estuary, at the points under which the tunnel passes, is 1,320 yards, the distance between the pumping-shafts being 1,770 yards. The Liverpool shaft was lined with cast-iron tubbing, excepting those portions which were in solid rock, not yielding much water.

The cast-iron tubbing (Plate 4) is of the ordinary design, and consists of segments with the flanges on the concave side. They are fixed just as they come rough from the foundry, the joints being made of red-pine timber sheeting, 2½ inches wide and ⅜ inch thick, which, when all the tubbing is in place, is wedged tight by driving in very dry timber wedges, until even a chisel-point will not enter. At Birkenhead it was found unnecessary to do more than line a portion of the shaft with tubbing, where water-bearing strata occur between layers of sound rock. In this case a crib was set upon a properly prepared bed, and at the upper end an "up-over" crib was fixed in a similar manner, except that it was reversed, the rock-bed in the latter case being on the upper surface of the cast-iron crib. The space between the tubbing and the rock is usually filled with ordinary mould, or peat soil, but in this case no filling was provided. Under the advice of Mr. William Coulson, of Durham, a pipe, 2 inches in diameter, was provided, connecting the space behind the tubbing with the open air; this pipe being carried through the upper crib, and continued up the shaft to above the ordinary water-level. The object of this

pipe was to allow any gas or air to escape, which otherwise might accumulate behind the tubbing, the pressure caused by such an accumulation having often proved destructive elsewhere. The Author does not attempt to explain how it is that the pressure, under any circumstances, should be greater than that due to the hydrostatic head, but such it is stated to be by those having extensive experience of pit tubbing.

Near the bottom of the shafts, standage headings, each having a capacity of 80,000 gallons, were driven, to secure to the miners sufficient time for escape, in the event of an accident to the pumps, or a sudden influx of water.

The pumping machinery at Liverpool consists of a pair of pumps, 20 inches in diameter by 6 feet length of stroke, connected by means of quadrants with a compound-engine manufactured by Messrs. Hathorn, Davey and Co., of Leeds; the low-pressure cylinder has a diameter of 35 inches, and the high-pressure cylinder a diameter of 20 inches, the length of stroke being 6 feet. The engine is fitted with their differential valve-gear, by which the supply of steam is automatically regulated according to the actual work done, and it has saved the pumping-machinery three times out of four when serious accidents threatened some portion of the machinery; also a pair of pumps 30 inches in diameter, of a similar character to those used at the well-known Whitburn sinking, near Sunderland, and driven by similar engines, having cylinders 60 inches and 33 inches in diameter respectively, and a length of stroke of 10 feet; and, lastly, of one pump 40 inches in diameter and 15 feet length of stroke, driven directly by an overhanging beam-engine, manufactured by Messrs. Andrew Barclay and Son, of Kilmarnock (Plate 4). In all cases care has been taken to provide pumps of sufficient diameter to enable both buckets and clacks being drawn from the top if required. The bucket- and clack-doors are also of ample size, to allow of their being changed at the door. The engine for the 40-inch pump is compound; the high-pressure cylinder has a diameter of 36 inches, with a length of stroke of 10 feet 6 inches, and a low-pressure cylinder 55 inches in diameter, with a length of stroke 13 feet, both cylinders being double-acting. This engine is of the type introduced by Mr. Barclay, and was adopted on account of its small liability to accident, and economy of floor-space. It is fixed vertically on its foundations near the mouth of the shaft.

The balance-beam of the engine is placed between the foundation-walls; this beam is 19 feet long from rocking centre to centre at the pump-rods, and 24 feet 6 inches long from the rocking

centre to the end, the back end being furnished with a box having sufficient capacity to hold 20 tons of balance-weights; its depth is 4 feet 6 inches, and it is composed of steel plates, $1\frac{1}{4}$ inch thick, securely bound with distance-pieces of cast-iron. The main beam of the engine is composed of two plates, each 32 feet 6 inches long, between the extreme centres.

A connecting-rod, 38 feet 9 inches long, unites the point of the main-beam with the point of the balance-beam; this rod is composed of oak, with malleable-iron straps. At each side there is a malleable-iron rod, extending from the main-beam to a cast-iron crosshead below the point of the balance-beam. To it the pump-rods are attached, thus bringing these rods directly on to the main-beam, on which there is but $1\frac{3}{8}$ inch of lateral motion, and avoiding the swing at the point of the balance-beam. The fact of the rods travelling upwards and downwards, almost in a direct line, gives great smoothness of working, even with the long stroke of 15 feet. The pump-rods are made of wood, having four malleable-iron plates at each joint; the rods are bolted to malleable-iron forks, having tapered ends turned and fitted, one end to the cast-iron crosshead at the top, and the other to the plunger at the bottom.

The pump is of the ordinary plunger pattern, having a length of stroke of 15 feet, and a diameter of 40 inches, and is turned true throughout its entire length, the suction and delivery valves are of brass, mounted with strong steel lids having leather faces, malleable-iron guards, and fishing tackle. The working barrel is bored its entire length, slightly larger than the plunger; the clack-seats are provided with openings, 4 feet 6 inches by 3 feet 9 inches, to allow of easy access to the valves; the doors for these openings are of steel. The whole pump is set on two massive cast-iron girders, the suction pipe passing up between them. These girders rest at each end on oak bedded in concrete, set on strong cast-iron boxes fixed on the solid rock, at the bottom of the shaft, below the water-level.

The machinery at Birkenhead is similar to that above described, with the addition of a second 40-inch pump, with a 15-feet length of stroke.

Arrangements are made by which the water from both sides of the river can be collected at either shaft, thus giving ample facilities for any repairs to the engines or pumps. The capacity of the machinery, at ordinary working speeds, is 18,800 gallons per minute, and the quantity of water, to be permanently dealt with, is from 7,000 to 8,000 gallons per minute.

From each shaft the drainage-heading was driven under the

river towards the centre, rising with gradients of 1 in 500, and 1 in 900. This heading was at first driven from both sides by hand, but the Birkenhead face was afterwards excavated by means of the Beaumont machine, which bored out a circular heading 7 feet 4 inches in diameter, somewhat resembling in appearance the rifling of a cannon. Hand-labour was stopped on the 15th of February, 1883, and the Beaumont machine taken down the shaft, and put in position at the face. The machine started work on the 26th of March, 1883, and by the 17th of January, 1884, the Birkenhead heading had been driven 696 lineal yards, and met the Liverpool heading, which was entirely driven by hand. This gave an average weekly progress of 17 yards, or, including the time taken in setting up the machine, of 14½ yards. The maximum week's work in this heading was 34 yards. The machine was afterwards slightly modified, and the cutters were better adapted to the rock; and during January 1885 the rate of progress was 54 yards per week through similar rock in a loop-heading. In the softer rock, met with in the Liverpool ventilation-heading, a speed of 65 yards per week was attained. The speed of driving by hand has been between 10 and 13 yards per week, giving a 9 feet by 8 feet heading, a size large enough for working double roads. The heading of 7 feet 4 inches diameter, produced by the Beaumont machine, requires to be both heightened and widened before it can be used, in order to work "break-ups." Only portions of the heading are lined, the rock being, for a greater part of the length, strong and solid.

It is remarkable that the wettest portions of the driftway were those under the land, and that, so soon as the work was proceeding under the river, the yield of water, in proportion to the area exposed, diminished. This is believed to be the result of clay and sand in the river filling the interstices of the rock.

For a portion of the drainage-heading, recourse was had to "plank tubbing," which answered admirably.

The setting out of this heading was a matter of some difficulty, and was carried out, with great precision, jointly by Mr. Irvine, the Resident Engineer, and by Mr. Davidson, the Contractor's Engineer. A correct survey was first made of the river, and the positions of the shafts were fixed by means of triangulation. As high warehouses intervened, the centre line had to be transferred to points on their roofs. As will be seen from Plate 3, the pumping shafts are not upon the centre line, that at Liverpool being connected with the heading by a cross-cut nearly at right angles, and 30 feet long, and that at Birkenhead by a cross-cut at an angle of 133°,

and 103 feet long. It therefore became necessary to set out lines at the proper angles to the shafts on the surface. German silver wires, 23 B.W.G., or $\frac{1}{40}$ inch in diameter, were then suspended in the shafts, weighted with plumb-bobs, weighing 33 lbs. each, and arranged in correct line by means of a fine-threaded screw-adjustment, which allowed lateral movement. The shafts being used for pumping purposes, it was difficult to ascertain whether the wires were hanging free, and it was decided to test them electrically. By interposing a galvanometer between the battery and the plumb-bob, it was readily ascertained whether the wires, at any point, were in contact with the surrounding machinery or pumps.

The instruments used were a 5-inch transit theodolite, by Messrs. Troughton and Simms, and a 6-inch transit theodolite, by Messrs. Cook and Sons, of York, which latter was fitted with a special screw-adjustment under the bottom plate, by means of which the instrument (set up as close to the wires as possible) could be brought into the line of the wires below, to within one-third of their diameter, or $\frac{1}{120}$th of an inch.

It was found by trial that the lines could be transferred down the one shaft, which was on the centre-line of the tunnel, and with a wire base of 10 feet 5 inches, with an extreme error below of no more than $\frac{1}{8}$ inch in 433 feet; the operation being performed three times, starting each time from the surface line. At the other shafts, where angles had to be measured and re-set off, such accuracy could not be expected, but was sought for by taking the mean of a larger number of observations. The Birkenhead lines, which were prolonged to the junction of the headings, were thus the mean of eight observations, two of which, down the pumping-shaft, were worked from a 9 feet 10 inches wire base, and six others, down the working-shaft, from a 9 feet 8 inches base. These were connected when a staple shaft had been sunk from the tunnel to the drainage-heading, at 470 yards from the shaft. The same was done with the Liverpool lines at the staple shaft, 295 yards riverwards, past which the mean of five trial lines was carried to the junction.

The headings met at 1,115 yards from the Birkenhead working-shaft, and 639 yards from that at Liverpool, with an error of 1 inch in meeting, and of $2\frac{3}{8}$ inches maximum error at the centre from the true line as afterwards ranged through, both lines having diverged slightly to the south. As might have been expected, there was less error in the lines taken down by the working-shafts, 95 feet deep, than in those through the pumping-shafts, with bobs suspended at a depth of 163 feet.

Landwards, the lines were checked at temporary air-shafts, at 490 yards from the Birkenhead working-shaft, where, after going round 28° of a 15-chain curve, there was an error of $2\frac{1}{8}$ inches, and at 400 yards from the Liverpool shaft, where, after going round 35° of a 10-chain curve, there was an error of $1\frac{3}{4}$ inch. These were so insignificant that it was not necessary to alter the lines below ground, the tangent being adhered to up to the next curve in each case. Throughout the whole of this work the instrument, although kept in good adjustment, was never assumed to be correct, but inverse observations were made, and the mean point determined. This was done repeatedly for each point in transiting, these points being marked at intervals of about 80 yards as the work went on, longer sights being often prohibited by the smoky atmosphere.

The levelling was an easier process; the only special difficulty being due to the water from the roof in wet places before the lining was built.

The width of the river made it practically useless to try to level across it, and as small discrepancies between the neighbouring Ordnance benchmarks were discovered, the datum was fixed, on each side, from the mean result of several of them. The levels were transferred down the shafts by carefully checked steel tapes, and the final result was that when the headings met, on the 17th of January, 1884, a point which had been fixed as being 129·05 feet above datum, as levelled from Birkenhead, was found to be 129·04 feet above datum, as levelled from Liverpool. This afforded proof of the general accuracy of the Ordnance levels on each side of the Mersey. This work was carried out under great difficulties, the quantity of water being very large, and the ventilation often imperfect.

So long as the excavation in the tunnel or driftway was carried on by hand, and blasting used, bore-holes were kept in advance of the face, but when the Beaumont machine came into play, these were considered no longer necessary. Safety, or flood-doors, were provided, but, at the request of the workmen, they were removed, nor did any occasion arise for their being made use of.

The rock extends throughout the whole length of the heading, and is fairly homogeneous, but rather harder on the Birkenhead than on the Liverpool side. Only one fissure was found; this was 10 inches in width, filled with disintegrated sandstone and clay, and close to it the rock was much broken up, necessitating careful timbering. Much more water was found on the Liverpool side than at Birkenhead, the rock being considerably more broken

up at Liverpool. The beds in the rock dip to the east, at an inclination of about 1 in 14. The heading was connected with the main works of the tunnel by small staple shafts and bore-holes, by which the works were kept free from water.

It was at one time intended to run the drainage-heading underneath the main tunnel, below the centre of the river, but it was afterwards decided to lower the levels of the tunnel, and loop-headings were driven by the Beaumont machine to connect the drainage-heading proper. The water from the land tunnels is carried along the top of the invert of the main tunnel in a brick culvert, of 1 foot 9 inches radius, until it finds its way into the drainage-heading.

The drainage arrangements have proved very efficient; and have resulted in the tunnel itself being remarkably dry. On the occasion of the opening of the tunnel by H.R.H. the Prince of Wales, the tunnel was lighted by gas, and thousands of visitors walked through from end to end, without so much as seeing a drop of water, the only complaint being that it was slightly dusty.

In the improbable event of all the pumps (six distinct sets) stopping at the same time, the standage capacity of the drainage-heading is sufficient to prevent the water rising so high as the rails in the tunnel for a period of five hours, thus giving ample time for any ordinary repairs.

One of the chief difficulties to be encountered was to keep the brickwork clear of the dripping water until the cement had set. This was accomplished by lining or roofing the top of the excavation in the tunnel with thin sheet-iron, or brattice cloth. The work was very carefully done, and the water led away to holes left near the invert. After the cement had thoroughly set, the holes were plugged up. The Author is of opinion that the remarkable dryness of the tunnel is, in no small degree, due to the care and attention that was devoted to this particular feature of the work.

River Tunnel.

The tunnel (Plate 4) is 26 feet in width, and, where in rock, is lined and inverted with brickwork in cement 2 feet 3 inches in thickness, the two inner rings with headers being of brindle brick. It is 19 feet high from the rails to the intrados, or 23 feet from the invert to the intrados, and it is provided with recesses for the platelayers on each side, at distances of 45 yards. After the work was commenced, additional intermediate borings were made, near

the Liverpool shore, in the positions pointed out by local geologists as being probably the ancient course of the river-bed, and it was found that there was a depression in the rock at this point. The tunnel here has a total cover of 70 feet; but, for a length of 66 yards the crown is, to the extent of from 3 to 6 feet, above the level of the sandstone rock, and passes through a thin layer of red clay and sand, covered with strong brown clay. The tunnel was put in by well-timbered lengths of 9 feet only, and the brickwork in the crown was thickened to 3 feet: no difficulty was otherwise experienced. The remainder of the tunnel was proved to be in rock by boring upwards from the headings to a height of, in every case, 15 feet above the crown of the tunnel.

The minimum amount of cover between the extrados of the arch and the bed of the river is about 30 feet, and the depth of water at high tide is 100 feet. The tunnel was carried out by means of a heading driven through at all speed, and numerous break-ups, so that at one time work was proceeding from twenty-four faces, the whole being well drained by the arrangements previously described. Additional shafts were sunk both at Birkenhead and at Liverpool for winding purposes, and these were closed upon the completion of the works. The rock was brought to these shafts by inclined planes, worked by steam-engines, and was then carted away, excepting such portions as were used for rubble masonry and bottom ballast.

Explosives.

The whole of the 320,000 cubic yards of rock excavated in the tunnel, and more than 60 per cent. of that excavated in the drainage-heading, were taken out by hand-labour. No large shots, such as are made use of when using drilling-machines, could have been adopted without danger of letting in too much water, when under the river, or of annoying the neighbourhood, when under the town. Dynamite was at one time tried, but was given up because of the noxious fumes.

Gelatine, manufactured by the Nobel Company, was used to a limited extent, and proved to be very efficient, especially in heading-shots. With this explosive an increased rate of progress of 2 yards a week in headings could be made, as against other explosives tried. The explosive, however, which was mainly depended on throughout was cotton-powder, or, in mining parlance, "tonite," manufactured by the Cotton Powder Company, Faversham. Of this explosive about 120 tons were employed, and

it proved to be both safe and reliable, as well as most efficient in doing its work under exceptional conditions.

Land Tunnels.

These tunnels are of similar dimensions internally to those of the river tunnel, and are generally lined with 18 inches of brick-work, no invert being added where the tunnel is in solid rock.

In some parts it was necessary to thicken the lining, owing to the rock being soft; and at Birkenhead, where the railway passes under the Joint Railway in soft ground, special construction was adopted. It was found at this point that the foundations would be in wet sand, and it was decided not to attempt to underpin the Joint Railway, which is itself in covered way.

The ground was opened from the surface; the covering and the walls of the railway were removed; balks were placed under the rails, and a closely-timbered excavation was carried down to the depth of the foundations. A strong concrete invert, surmounted by a tunnel in brickwork, was then constructed, and the works of the Joint Railway rebuilt.

Covered Ways and Retaining Walls.

A portion of the railway was constructed by cut-and-cover, that under the Joint Railway property having side-walls of concrete faced with brickwork and an invert of concrete, that under Borough Road having also side-walls and an invert of concrete, carrying wrought-iron girders with brick arches between.

A short length near the junction, and the Borough Road station ground, are retained by walls of rubble masonry, to a great extent constructed of stone brought from the tunnel.

The total number of bricks used in the lining of the tunnel and headings, and in the covered way, was 38,000,000. The two inner rings are of blue Staffordshire bricks, made by Joseph Hamblet, West Bromwich. The four outer rings are of red wire-cut bricks, supplied by the New Ferry Company, Cheshire, the New British Company, Ruabon, and the Brymbo Coal and Iron Company, Brymbo. Buckley "brindle" bricks were also used for the upper rings of the invert, being found to hold the cement better than the smoother blue bricks. The brickwork is almost all in cement, in the proportion of either 3, or in some parts, 2 to 1.

Stations.

Green Lane station is partially open, the Joint Railways of the London and North Western Railway and Great Western Railway Companies being carried over one side of it, by means of wrought-iron girders. The Borough Road station is an "open-air" station, and here are situated the locomotive-sheds and the carriage-sheds of the Company, with small repairing-shops, and the necessary gas-works, erected by Messrs. Pintsch and Co., for supplying the rolling-stock with gas. The Hamilton Street and the James Street (Plate 4) stations are excavated in the solid rock, and being near the river are necessarily at great depth; the rails at James Street are about 90 feet, and at Hamilton Square 100 feet, below the level of the booking halls. They are 400 feet long by 50 feet wide by 32 feet high, and are arched with brickwork in cement, 2 feet 3 inches in thickness, and lined, to a height of 12 feet above platform-level, with white glazed bricks, the subways hereafter referred to being lined in like manner. The platforms are connected by groined passages and a foot-bridge with an underground hall. From this hall open out: a foot-subway, 10 feet in width, leading by an incline of about 1 in 9 to the surface; a staircase of more than one hundred and sixty steps; and three passenger-lifts, each giving a floor-area of 340 square feet in the cage, and having a stroke at Birkenhead of 87 feet 9 inches, and at Liverpool of 76 feet 6 inches. These lifts and the staircase lead to the upper booking-hall, on a level with the public street, which is connected with the usual waiting-rooms and other conveniences. The station buildings, the architectural details of which were prepared by Mr. G. E. Grayson, of Liverpool, include hydraulic towers, in which are placed the water-tanks for the working of the hydraulic machinery. At James Street the upper floors above the station are utilized for extensive chambers.

Temporary sidings are laid in at James Street for shunting the trains, so that the traffic may run for the present between Green Lane and James Street Stations.

Hydraulic Lifts.

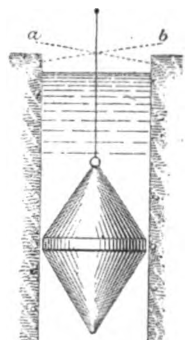
The lifts, which have been manufactured by Messrs. Easton and Anderson, MM. Inst. C.E., are, it is believed, the largest yet constructed for passenger purposes.

After careful consideration of different proposals, it was decided that, to secure safety, a direct-acting ram, working at a compara-

tively low pressure, should be adopted. This necessitated the sinking of wells 40 inches in diameter and 90 feet in depth, for the reception of the cylinders, into the Red Sandstone rock; and, as time was of great importance, it was decided to place the work at James Street, Liverpool, in the hands of Messrs. Mather and Platt, of Salford, whilst Messrs. Timmins, of Runcorn, undertook the sinking of those at Hamilton Square Station, Birkenhead. The method adopted by Messrs. Timmins was to bore a hole, 18 inches in diameter in the first instance, to a depth of 90 feet. The hole was then carefully plumbed to ascertain if it was in any degree out of truth, and if so to what extent. This decided the size of the widening-out bar. It was then increased in diameter to 36 inches. The plumbing of the holes involved a good deal of thought, owing to the wells being in all cases full of water. The plumb-bob consisted of a double cone, each cone being 3 feet in length, and 39 inches in diameter at the centre.

This was suspended from a point 95 feet above the top of the well, cross strings being carefully fixed, as at *a b* in Fig. 1.

Fig. 1.



If the plumb-bob in its descent to the bottom of the well encountered any irregularity, the exact amount could be calculated by the travel of the plumb-line at the cross strings. In the case of the Liverpool wells the plumb-bob was also 39 inches in diameter. The three wells which were sunk at James Street Station were bored by Messrs. Mather and Platt's earth-boring machine, to the full diameter of each well, namely 40 inches, being bored at one operation. The bar when boring obtained the necessary percussive motion from the steam percussion-cylinder of the boring-machine, and after working a sufficient time in the bore-hole, was withdrawn, by means of a winding engine, also attached to the machine. The shell-pump was then lowered by the same winding engine, and by it the material broken up by the cutters of the boring-bar was withdrawn. These operations were successively performed until the required depth of the well was reached. Each of the holes when completed was perfectly round and plumb. In No. 1 well boring was commenced on the 23rd of March, 1885, and finished on the 11th of April. The depth bored was 76 feet 6 inches. The number of days occupied in boring was eighteen, and the average depth bored per working day was 4 feet 3 inches. The boring of well No. 2 was commenced on the

20th of April, 1885, and it finished on the 5th of May. The depth bored was 76 feet 9 inches. The number of days occupied in boring was fourteen, and the average depth bored per working day was 5 feet 6 inches. No. 3 well was commenced on the 25th of May, and it was finished on the 8th of June, 1885. The depth bored was 76 feet 10 inches, the number of days occupied in boring being thirteen. The average depth bored per working day was 5 feet 11 inches, and the work was carried on night and day. At Hamilton Street Station the wells were also 40 inches in diameter, but the depth was about 88 feet in all cases, the work being carried out with a heavy cutter, which was raised by means of the friction of a rope on a constantly revolving drum. By slacking the end of the rope which was held by the man in charge, the friction was reduced and the tool dropped. This method required far less preparation than that adopted at Liverpool, but there was little difference in the date of the completion of the wells at the two places.

In each of the stations there are three lifts, each arranged to accommodate one hundred passengers at a time. The time occupied on the vertical journey is about forty-five seconds, so that a train-load of three hundred passengers can be brought from platform-level to the surface in one minute. The lift consists of a room, or cage, 20 feet long, 17 feet wide, and 8 feet to 10 feet high, with seats on each side, and is fitted with handsome panelled sides of teak and American ash, and with a lantern-roof surrounded by mirrors, with a central gas-lamp.

The cage is supported on a stiff frame of iron girders, riveted to a central forged-steel cross, which at its centre is fitted to a hollow steel ram, 18 inches in diameter, which rises and falls in a strong hydraulic cylinder suspended in the well. A safety-bolt, passing through the ram, is firmly secured to the floor of the cage.

In the tower at the stations, at a height of about 120 feet above the pavement, there is a supply-tank holding 10,000 gallons of water, and at a depth of about 60 feet below the pavement there is a waste tank of similar capacity. The hydraulic pumping machinery is fixed on a floor intermediate between the upper and the lower booking-hall in the station. In the engine-room at James Street there are three marine boilers, and three pairs of Messrs. Easton and Anderson's duplex pumping-engines, each of which is capable of raising 30,000 gallons of water per hour, from the waste-tank below, back to the supply-tank in the tower above. These engines are also so connected that they can supply the lifts direct, either acting in unison with or without the supply-tank. An arrangement of interchangeable valves and pipes in the

engine-room enables any main pipe, pumping-engine or lift to be shut off readily without disturbing any other part of the system. The lifts were severely tested by General Hutchinson of the Board of Trade on the 29th of December, with loads equal to about one hundred and forty passengers concentrated on one side of the cage, and they stood these tests most satisfactorily.

Ventilation.

The ventilation of the tunnel and of the stations has been the subject of much consideration. In the ventilation of mines the great aim of the mining engineer is to secure a constant current of fresh air in given directions, and to ensure this, all the roadways and workings, which branch off from the main air-ways, are either supplied with double doors, or are stopped by being bricked up and plastered over. In the Metropolitan and Metropolitan District Railways, holes have been cut in the roof of the tunnel communicating with the outer air. Through these holes the products of combustion are doubtless to some extent expelled, and fresh air is drawn in; but, in the absence of a complete system of mechanical ventilation, the result cannot be satisfactory.

The only practical method of dealing with the impure air in such cases is, in the Author's opinion, the adoption of ventilating fans placed about midway between the stations, by which a steady and continuous current of fresh air will flow in at each station, and thence through the tunnel to the fan. The air throughout the tunnel is thus changed, and not merely churned backwards and forwards.

The principle laid down for the ventilation of the Mersey Tunnel was that fresh air should enter at each station, and "split" each way into the tunnel. By this means the atmosphere on the platform is maintained in a condition of purity. The air has then to travel towards a point midway between the stations, whence it has to be extracted from the tunnel by means of the ventilating fans.

The first point to arrive at was the quantity of air required. Taking the consumption of fuel at 40 lbs. of coal per mile, the service of trains at five-minute intervals in each direction, equivalent to one train passing every two and a half-minutes, the greatest distance between the stations, namely, from James Street to Hamilton Square, as a little over 1 mile, and the quantity of noxious gas eliminated at 29 cubic feet per lb. of coal, the result is

464 cubic feet of noxious gas generated per minute. This, diluted to the extent of 1 in 500, would require 232,000 cubic feet of fresh air per minute to be drawn from the tunnel, or an average duty of 116,000 cubic feet per minute by each of the two fans hereafter described.

The air-drift was cut by the Beaumont boring-machine, and is circular in form, 7 feet 4 inches in diameter, and almost as true and smooth as a gun-barrel. It extends from Shore Road, Birkenhead, to Whitechapel, Liverpool, a length of about 2,250 yards.

It is connected by means of sliding-doors with the tunnel and the stations, so that the air can be extracted from any point desired.

Engines and Fans.

The fans are somewhat similar to the well-known Guibal fans, excepting that in the shutter (to which Guibal attached the chief value of his patent) an important alteration has been made. With the Guibal shutter the top of the opening, into the chimney from the fan, has a line parallel to that of the fan-shaft and of the fan-blades, and, as a consequence, as each blade passes this shutter, the stoppage of the discharge of the air is instantaneous, and the sudden change of the pressure of the air on the face of the blade whilst discharging, and the reversal of the pressure, due to the vacuum inside the fan-casing, causes the vibration hitherto inseparable from this type of ventilator.

Immediately at the opening into the chimney (*i.e.* at an angle of 45° from the horizontal line), this regulating-shutter, which has a Λ-shaped opening into the chimney, commences, and tapers to a point near the cross-girder which supports the chimney. The result of this gradually decreasing opening is to allow the air to pass in a continuous stream into the chimney, instead of intermittently, as was formerly the case, and to allow the change of pressure from the front to the back of the blade to be imperceptible, the action of the fan being thus rendered noiseless, and with an entire absence of vibration. To suit the varying circumstances under which fans have to work, the apex of the Λ can be raised or lowered.

As an illustration of the effect of the pulsatory action of the Guibal shutter; a fan having ten arms and running, say, sixty revolutions per minute, and working twenty-four hours per day gives ($10 \times 60 \times 60 \times 24 =$) 864,000 blows per day transmitted from the tip of the fan-vanes to the fan-shaft; the shaft is thus in a constant state of tremor, and sooner or later reaches its elastic

limit. The consequent injury also to the general structure of the fan is obvious. The regulating-shutters are practically indestructible, being of wrought-iron plates, made very strong, and stiffened where necessary with angles and T-irons.

The action of this patent regulating-shutter has an important bearing upon the working of the ventilating-fans in their consequently increased durability and efficiency. In towns, like Liverpool and Birkenhead, any pulsatory action would be readily felt by the inhabitants. It is difficult to detect any sound whatever when standing close to the buildings containing the fans. The air is admitted on both sides, as it is found in practice that the fans run much more smoothly, and with the absence of the side thrust attendant upon those which have the air admitted on one side only.

The fans (Plate 4) are four in number: two are 40 feet in diameter by 12 feet wide, and two 30 feet in diameter by 10 feet wide, one of each size being erected at Liverpool and at Birkenhead respectively.

The engines for working the fans are all similar in design and construction, and are of the horizontal type, each fan having a compound tandem condensing engine with a horizontal condenser. and also a simple high-pressure stand-by engine, coupled direct to the fan-shaft: a very short time only is required to change from one engine to the other. For the 40-feet fans the high-pressure and low-pressure cylinders of the compound engine are 20 inches and 33 inches in diameter respectively, by 2 feet 6 inches length of stroke. The stand-by engine has a cylinder 33 inches in diameter by 2 feet 6 inches length of stroke. The engines of the 30-feet fans have, for the compound engines, high-pressure and low-pressure cylinders, 15 inches and 24 inches in diameter respectively, by 2 feet length of stroke. The stand-by engine has a cylinder 34 inches diameter, by 2 feet length of stroke.

As water for condensing purposes is not readily available for the fan erected in Hamilton Street, Birkenhead, the exhaust steam is cushioned, and rendered noiseless by being turned into a receiver before passing into the atmosphere, but advantage is taken of this by placing, inside the receiver, a water-heater, through which the feed-water for the boilers passes.

Each fan is supplied with a Harding's counter, worked by means of an eccentric on the fan-shaft, a steam-pressure gauge, a vacuum-gauge, and a water-gauge, the latter having a communication with the fan-drift by means of a short pipe. The engines throughout are made very strong, and careful attention has been

paid to every detail, so that any accident thereto is of very unlikely occurrence. An overhead traveller is fixed over each fan-engine.

For the purpose of ventilation, the tunnel is divided into four sections, one of the above fans being allotted to each; but two fans at Liverpool and one fan at Shore Road, Birkenhead, can at any moment, through the medium of doors in the air-headings and passages, be made to do each other's duty as well as their own, and by this means any complete stoppage in the ventilation of the tunnel is rendered impossible.

The 30-feet fan erected at Liverpool ventilates, through the medium of a portion of the air-heading, the James Street station (connections being made from the roof of that station to this air-heading) and also the section lying between the said station and the terminus. This fan exhausts about 120,000 cubic feet of air per minute.

The 40-feet fan erected in Liverpool, ventilates the section of the tunnel lying between the James Street station and the centre of the river, there being "smoke-holes" at intervals between the main tunnel and the air-heading. This fan exhausts about 130,000 cubic feet of air per minute.

The 40-feet fan at Shore Road does similar duty to the 40-feet fan working at Liverpool, and ventilates the section lying betwixt the middle of the river and the Hamilton Square station at Birkenhead, there being "smoke-holes" also connecting the main tunnel and the air-heading. This fan, in addition, will ventilate the Hamilton Square station, by means of "smoke-holes" in the roof, which are connected with the fan by a separate air-way. The air exhausted by this ventilator is about 130,000 cubic feet per minute.

The fourth fan, of 30-feet diameter, exhausting about 200,000 cubic feet of air per minute, is erected in Hamilton Street, nearly midway betwixt Hamilton Square station and Borough Road station. This fan is connected directly to the main tunnel by a shaft 12 feet in diameter, and a cross-cut at the bottom of the shaft to the tunnel of similar sectional-area, and ventilates the tunnel between the two stations above named.

The fresh air enters through the respective stations, as well as through the entrances to the tunnel; but to relieve the stations from too strong draughts, the two pumping-shafts, the one at Liverpool, and the other at Birkenhead, are also used for the admission of fresh air, the quantity of which can be regulated.

At each of the "smoke-holes" connecting the stations and main

tunnel with the air-heading, doors are placed for regulating the volume of air passing through.

The total yield of the four fans amounts to 580,000 cubic feet of air per minute, or about one-seventh part of the total cubic capacity of the tunnel. There is a considerable margin between the duty of the fans as given above, and their maximum exhausting capacity.

The ventilating-fans and fan-engines were made and erected by Messrs. Walker Brothers, of Wigan, and the shutter already described is their patent.

Lighting of Stations.

Some surprise has been expressed at the non-adoption of electric light for the platforms and signals. The Author is, however, of opinion that, so long as the smallest uncertainty exists as regards the regularity of electric light, a Railway Company is not justified in employing electricity as a lighting agent, unless gas is already laid on, so as to be readily available in case of breakdown of the electric-lighting machinery. Tenders were, however, invited both for gas-lighting and electric-lighting. The result of the tenders was remarkable. It was found that, allowing an equivalent light in each case, and excluding arc-lights, which for many reasons are objectionable in an underground railway, the first-cost of installing electric light would have been five times that of gas, and that the annual cost would be three times that of gas. It was therefore decided to adopt gas lighting; and this has been efficiently carried out by Messrs. Sugg and Co., who were represented on the work by Mr. S. R. Barrett. A 4-inch gas-main was laid through the tunnel, and connected at Liverpool with the mains of the Liverpool Gas Company, and at Birkenhead direct with the gas-holder of the Birkenhead Corporation. By these means, ample pressure has been obtained for lighting the lowest portions of the tunnel, whilst any waste of gas from the high pressure is effectually prevented by the automatic governors fixed inside each burner.

Permanent Way.

This railway having necessarily steep gradients, namely, a short length of 1 in 27, and considerable lengths of 1 in 30, with curves of 8 and 9 chains on the main line, it was deemed necessary to adopt permanent way of great strength.

The rails are of steel, of the bull-head section, weighing 86 lbs. to the yard, with deep fish-plates, and fixed in chairs weighing

54 lbs. each. The rails bear upon wooden cushions recessed into the chairs. To meet the requirements of the Corporations of Birkenhead and of Liverpool, two thicknesses of felt are inserted under each chair.

The sleepers, 10 feet long by 5 inches, are creosoted, and are laid closer together than usual, namely, thirteen sleepers to each 30 feet of rail. The ballast is composed of sandstone rock from the tunnel, carefully packed by hand into the invert to within 4 inches of the bottom sleeper, then of broken sandstone rock for a thickness of 4 inches, the top ballast being dry clinker ashes, 6 inches in thickness.

Signals and Telegraph.

The signals were manufactured by the Railway-Signal Company, Fazakerly; the telegraph, telephone, and electric-repeating arrangements having been carried out by Mr. John Lavender, of Manchester. Catch-points are inserted at several places, and the signals in the tunnel are fitted with gongs to attract the attention of the driver.

Locomotives and Rolling-Stock.

The locomotives, which have been specially designed for this railway, have been manufactured by Messrs. Beyer, Peacock, and Co., and the carriages by the Ashbury Carriage Company. The locomotives are six-wheeled, coupled tank-engines, with a four-wheeled bogie, making ten wheels in all, and have inside-cylinders, 21 inches in diameter, by 26 inches length of stroke.

They weigh, when in full working order, 67 tons 17 cwt. 1 qr., thus distributed—

	Tons.	cwt.	qrs.
Leading wheels	16	16	3
Driving "	17	10	0
Trailing "	17	5	0
Bogie "	16	5	2

Each locomotive is provided with a powerful steam-brake, as well as with an automatic vacuum-brake, and with the condensing-apparatus as used on the Metropolitan Railway. They are designed for trains of 130 tons gross, exclusive of their own weight.

The passenger-carriages are carried on four wheels, and are 27 feet long over the bodies, by 8 feet wide. The wheels are of special manufacture, giving increased strength to resist torsion. The wheel-base is 15 feet 6 inches.

The trains are fitted with the automatic vacuum-brake, and lighted by gas upon Pintsch's system.

Extensions.

The Company is now proceeding with its authorized extensions, as already described. The necessary junctions with the main line for these extensions have been already constructed, so far as excavation and brickwork are concerned.

The junction at Birkenhead is an ordinary double junction, and the one at Liverpool is a "fly-over" junction, to avoid any crossing on the level on the steep gradients.

Conclusion.

The work herein described, including the purchase of property, rolling-stock, Parliamentary and all contingent expenses, has cost about £500,000 per mile of double railway. The work on the whole, considering its special and somewhat difficult character, has been remarkably free from accident.

The Inspector of the Board of Trade, Major-General Hutchinson, R.E., sums up his report upon it as follows:—"In conclusion, I think it only just to remark that great credit appears to be due to the Engineers and Contractors, who have so ably carried out, and brought to so satisfactory a conclusion, this great and important work."

The Chairman of the Company is the Right Hon. Henry Cecil Raikes, M.P., and the Deputy-Chairman the Right Hon. E. Pleydell Bouverie; the joint Engineers of the Company are, Sir James Brunlees, Past-President, and Sir Douglas Fox, M. Inst. C.E., assisted by the Author; the Resident Engineer is Mr. Archibald H. Irvine, M. Inst. C.E., assisted by Mr. Ernest S. Wilcox; and the Contractors are Major Samuel Isaac, and Messrs. Waddell and Sons, represented by Messrs. James Prentice and D. A. Davidson.

This communication is accompanied by several diagrams, from which Plates 3 and 4 and the Fig. in the text have been engraved.

(*Paper No. 2177.*)

"The Hydraulic Passenger Lifts at the Underground Stations of the Mersey Railway."[1]

By William Edmund Rich, M. Inst. C.E.

A novel feature of the Mersey Railway, is the introduction of large hydraulic lifts for conveying passengers and their luggage, from the deep underground stations at James Street and Hamilton Street, to the daylight stations at the street-level above. In such situations these lifts may be looked upon practically as vertical branch-railways, and as such, a more detailed description of them, and of the apparatus connected with them (Plate 5), than that given in Mr. Francis Fox's Paper on the Mersey Railway Works generally, may be of interest to the Institution.

The rails, which rise with steep gradients in both directions from the centre of the tunnel, reach James Street Station near the Liverpool Exchange, at a depth of 92 feet below the street-level, and at Hamilton Street Station (the nearest to the river on the Birkenhead side) the rails are 103 feet below the street.

The object of the lifts is to relieve passengers making use of these stations of most of the fatigue of walking up and downstairs through the above vertical distances, and to convey them up and down much more quickly than would otherwise be possible.

In each station there are three lifts (Plate 5, Figs. 1, 2, 3), which are worked quite independently of one another, and are each capable of raising one hundred passengers at a time. The average journey is accomplished in from thirty to forty seconds, and the three lifts, working simultaneously, are capable of raising a train load of three hundred passengers to the surface in about a minute. The lifts are of the direct-acting ram type, having hollow steel rams 18 inches in diameter, with balance-chains and counterweights at the sides. The ascending-room, or cage, in each lift is 19 feet 6 inches long, by 16 feet 6 inches wide, and 8 feet to 10 feet high, all inside dimensions, and is constructed with handsomely panelled sides and roof of teak and American ash, with seats for twenty-four passengers along the sides, and a large gas lamp in the centre of the roof.

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[1] The discussion upon this Paper was taken together with that upon the preceding one.

The motive-power is water at a low pressure derived partly from a tower-tank holding 10,000 gallons, and partly from steam-pumping engines, discharging direct into the lift supply-pipes.

On the downward journey the water is discharged into the underground waste tank, from which it is pumped back to the upper tank by the engines. The lifts at James Street have a stroke of 76·6 feet, and those at Hamilton Street of 87·7 feet.

In consideration of the greater traffic which may be always expected at James Street, there are three boilers and three sets of pumping engines there, as against two boilers and two sets of engines at Hamilton Street; and the arrangement of this machinery in plan at the two stations is somewhat different; but for the purposes of this Paper it will be sufficient generally to concentrate attention on the detailed arrangements at James Street. The station-buildings there are on the west side of the street. The booking-hall on the ground floor is 46 feet long, 33 feet wide, and 19 feet high. On the south side are entrance doorways to the A and B lifts; and on the north side are doorways leading to the C lift, and a flight of stairs which also leads to the lower hall 76·6 feet beneath (Plate 5, Fig. 1).

The engine-room is intermediate between these two floors, being at a height of 27·2 feet above the lower hall. The remaining space between the engine-room and the booking-hall floors is occupied with floors for luggage, stores, porter's room, &c.

The lower hall is very similar in plan to the booking-hall above having doors similarly placed for access to the lifts and stairs, and in addition an arched opening on the west side forms the entrance to an inclined subway, leading towards the Exchange. On the east side are two open arches about 12 feet wide. The most northerly of these leads by a flight of broad winding steps to the up-line platform at a level of 12 feet 10 inches below the lower hall floor. The other arch gives access to the down platform on the opposite side of the tunnel station by means of a lattice-girder foot-bridge.

The station buildings are carried up to a considerable height above the booking-hall, and will probably be let out in offices, for the convenience of which a small passenger lift is provided. A tower rises above the main block of buildings, and contains at its upper end the top tank, 15 feet 6 inches diameter, 9 feet deep, which holds 10,000 gallons of water. The waste-tank of similar capacity is excavated out of the rock beneath the engine-room floor, and lined with brick in cement.

The several lifts are contained in rectangular vertical shafts,

21 feet long and 19 feet wide, partly excavated out of the solid red sandstone rock, which stands with clean dry vertical surfaces without lining, and partly enclosed in walls of brick in cement, which separate the shafts from one another, and from the engine-room, booking-hall, &c.

Each shaft descends to a depth of 8 feet below the lower-hall floor, and rises to a height of about 20 feet above the upper booking-hall floor. On each side of the shaft four vertical rows of wooden bricks, Figs. 3 (p. 66), are fixed in the walls with thin folding wedges. These bricks are cut out of pine sleepers, of a section 10 inches by 5 inches, and they are let into the walls, and project outwards from the faces of them. They are spaced at 5 feet apart vertically from centre to centre. To these wooden bricks eight lines of rails are attached with coach-screws; four of these rails serve for guiding the cage, and the remaining four for guiding the counterweights. These rails are of steel of the section shown in Figs. 3 (p. 66), and are in 15-feet and 10-feet lengths, connected by fish-plates. They were all specially straightened, and fixed accurately to gauges, so as to form very true guiding surfaces. The advantage of the V-shaped guiding surfaces is that the guide-brackets, which slide over them, can be efficiently adjusted as they wear, by packing them out in one direction only.

In the centre of each lift space, and vertically downwards from beneath its floor, a boring has been carried down to a depth of 75 feet, for receiving the lift-cylinders. The three borings, at Hamilton Street, were constructed by Messrs. Timmins, of Runcorn, with the old-fashioned jumping tackle, and they are about 35 inches inside diameter and 86 feet deep. Those at James Street were constructed by Messrs. Mather and Platt, with their well-known boring-tackle, with large boring heads specially constructed for the purpose; these borings are 40 inches diameter.

It is interesting to note that Messrs. Mather and Platt's tackle was much more elaborate than that of Messrs. Timmins, and many weeks were occupied in getting it rigged ready to start; but when once started, the rate of progress was more than twice as fast, and the work was more accurate, as regards verticality. It is of the utmost consequence that the cylinders of hydraulic lifts should stand truly vertically, and hence it is essential that the borings for receiving them must be as nearly plumb as possible, and sufficient extra diameter beyond that of the cylinder-flanges must be given to the boring, to provide for its possible lack of verticality. In London the Author has of late years adopted wells, 3 feet in internal diameter, for receiving lift cylinders, in

preference to borings, which give great trouble when they are out of plumb.

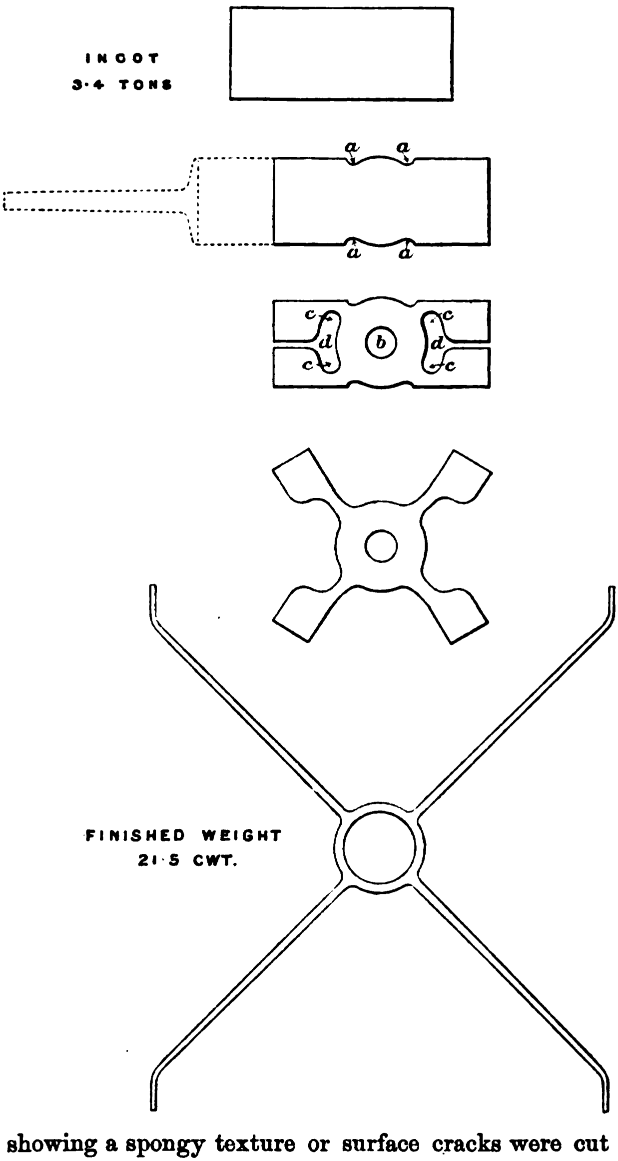
The cast-iron lift-cylinders are 21 inches in internal diameter, and 1⅛ inch thick, with strongly bracketed flanges, 29 inches in diameter, and they are bolted together in 12-feet lengths, with sixteen bolts 1⅛ inch in diameter to each joint, and suspended in the boring from the top length, which is furnished with a large bell-foot, 4 feet 8 inches in diameter, which rests on the floor of the lift space. This top length also has a tee-branch on the front side, for connecting it with the starting-valve, and at its top end it is bored out 18 inches in diameter, and fitted with a hat-shaped leather for making the joint round the ram. The ram, which descends into the cylinder, is 18-inches outside diameter, and ½ inch finished thickness, constructed of mild steel tubes, in lengths of about 11 feet 6 inches. These tubes are turned and polished, and connected together by internal screwed ferrules, 6 inches long, and 15¾-inches internal diameter, the screw-threads being eight to the inch. The bottom end of the ram is a tough heavy casting, with hemispherical bottom, and as an additional security, rods, 1½ inch in diameter at the smallest part, are attached to this bottom casting, and carried up the centre of the ram, so as to securely grasp the boss of the main cage-cross at its top end.

The tubes for these rams were forged by Messrs. James Russell and Co., of Wednesbury, from Landore-Siemens steel plates, ¾ inch thick. They were lap-welded in short lengths of a few inches at a time under a hydraulic press. The steel was tested by Professor Kennedy, and was found to break with a load of 63,000 lbs. per square inch, the average extension being about 29 per cent., and the contraction at the point of fracture 47 per cent. The ram preserves its uniform diameter of 18 inches to its top end, and there enters the boss of the steel cage-cross, and is attached to it with four 1¼-inch turned bolts with nuts and guard-pins.

The cage-crosses, which are shown in Figs. 2 (p. 64), were forged by Messrs. Clay, Inman and Co., of the Birkenhead Forge, and are considered very fine specimens of complicated steel forgings. Each cross in its finished state weighs 21½ cwt., and was forged out of an ingot weighing originally about 3·4 tons, supplied by the Steel Company of Scotland. Mr. Salmon, the managing director of the Birkenhead Forge Company, has furnished the Author with the outlines of the successive stages by which these crosses were forged (Figs. 2). He made a great point of discarding as a matter of course several inches of the original ingot near its top end, and before anything was done

the side surfaces of the ingot were carefully examined, and any

FIGS. 2.



parts showing a spongy texture or surface cracks were cut away by milling or slotting machines. In the first place the ingot was

drawn out under the hammer, and dented at *a a*. Secondly, the holes *b c c* were drilled, and the pieces *d d* slotted out; next the arms were drawn out straight to their full length; then the boss was bored, and its outside edges and the junctions of the arms with it were neatly slotted round. Finally the arms were bent away to form the feet, and the faces of these feet were planed off to gauge. Each cross measures 9 feet 6¼ inches wide over the feet, and 11 feet long, and the boss is 15 inches deep and 2 inches thick. The arms are 2 inches thick near the boss, and 1¼ inch thick, and 11 inches deep at their outer ends. The cross is riveted by means of the four feet at the ends of its arms to the vertical webs of two thick English rolled joists of H-section, 18 feet 8 inches long, 14 inches deep, and 6 inches wide; and these girders are further strengthened by riveting on to their top and bottom flanges iron plates, 12 inches wide, ½ inch thick.

These foundation girders are laid transversely beneath the lift-cages and are extended beyond their sides, to enable the counter-balance chains to be attached at their outer ends. The floor of the cage or ascending-room consists of eight pitch-pine joists, 10½ inches deep, those at the sides being 5½ inches thick, and the others 3¾ inches thick. Each of these is attached to the top plates of the main girders mentioned above by four stirrups of ¾-inch iron, screwed at the ends, and fitted with nuts beneath the flanges. At the front and the back of the cage these wooden joists are morticed into transverse timbers of the same depth as themselves, and 5½ inches thick. A teak floor, 1¼ inch thick, is laid on this timber framing, and the sides and ends of the cage formed of teak frames, 3 inches thick, with American ash panels, ¾ inch thick, are built upon it.

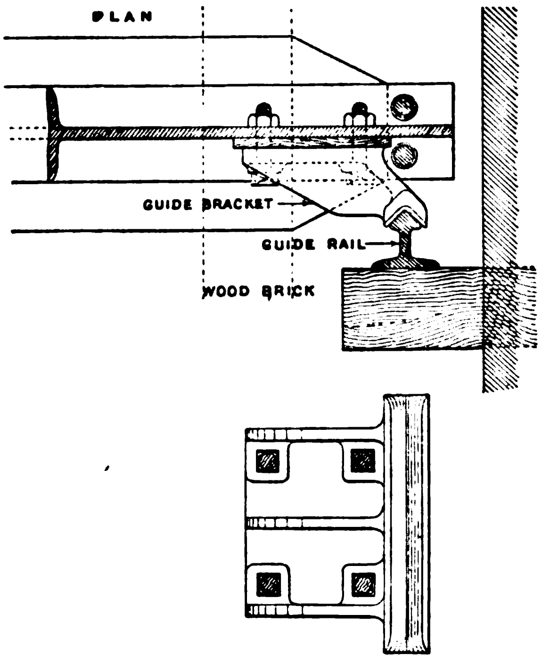
The roof of the cage is also panelled, with looking-glasses in the inclined panels to reflect the light of the central gas-lamp downwards. For a width of 2 feet round the sides the roof is of extra strength, having double boarding, so as to form a good gangway for inspection of and access to the working gear, and to support any loads which it may be convenient to lay upon them, in the case of overhauls or replacing chains, &c. There are spline seats on each side of the cage, and on the front side is the doorway, 4 feet wide, with sliding-door fitted with clear glass panels.

The ornamental panel-work was designed by Mr. Grayson, of Liverpool, the Architect for the station buildings, and the woodwork of the cages was constructed by the Starbuck Car Company, of Birkenhead.

The cage is kept in position, and guided from top to bottom of its stroke, by four cast-iron V guide brackets, 16 inches long, bolted to the flat sides of the vertical webs of the girders at their ends, and adjusted with wooden packings, so as to bear on the four steel rails above mentioned (Figs. 3). They can be easily removed, and thicker packings added as they wear away.

Above the lift-cage, at the top of its stroke, two Butterley rolled-joists, 16 inches deep and 5½ inches wide, span the lift-space crosswise, and on the ends of these, at a distance of 5 inches from the

FIGS. 3.



walls, two other joists of the same section are seated and securely bolted to them. From each of these side girders two chain pulleys, 4 feet 8 inches in diameter, are suspended by means of stirrups of forged plate-steel, with central turned bolts, 3 inches in diameter, furnished with trebly-secured attachments at their ends.

Between each pair of pulleys a counterweight is suspended by two 1⅛-inch short link chains, with an eyebolt and double nuts at one end of each, for attaching it to the weight.

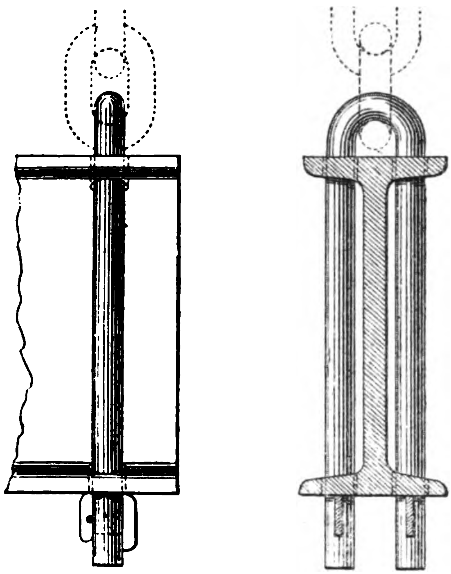
Each main weight weighs 7,620 lbs., and is fitted with recesses for receiving thirty-nine or any smaller number of weights of

90 lbs. each for balancing the lift; these may be very easily put on or removed by an attendant on the cage top.

The chains pass over the pulleys above-mentioned, and are attached by long U-shaped shackles and cotters (Figs. 4), to the ends of the cage girders.

It is noteworthy that no ordinary shackle will pass through the links of short-link chain. With these, however, a chain can be cut anywhere, and attached more securely than with common shackles, which the Author considers weak and unreliable devices for such responsible duties. The lift starting-valve is placed on the bottom floor of the lift space, vertically, beneath the cage

Figs. 4.



door; it consists of a gun-metal slide-valve, working on a cast-iron face. The supply port is shaped so as to enable the valve to be closed and opened without causing sudden shocks in the water, and through it to the lift-ram. The valve is actuated by a pinion working into the teeth of a rack cast on the back of the slide. The pinion is cast in one with the spindle, which passes through two stuffing-boxes in the sides of the cover, with a 4-feet rope-wheel on one end of it.

A hempen hand-rope, with wire-rope core, is attached at its two ends to this wheel, each end lapping three-quarters round it at half-stroke. This rope passes up through the lift-cage, on each

side of the doorway, and over two pulleys fixed at the top of the lift-space. The rope on the right-hand side of the doorway looking out is fitted with stops; so that the lift is arrested as it approaches the top and bottom floors by engagement with these stops, and so closes the valve.

A large self-acting flap-valve admits water automatically to the lift-cylinder from the exhaust, if the starting-valve is closed too suddenly during the ascent of the lift; and as the full stroke of the hand-rope from full pressure to full exhaust is 9 feet, it is found that the lift starts and stops with great quietude and comfort to the passengers. A lock on the hand-rope in the cage prevents any unauthorized person from actuating the starting-valve.

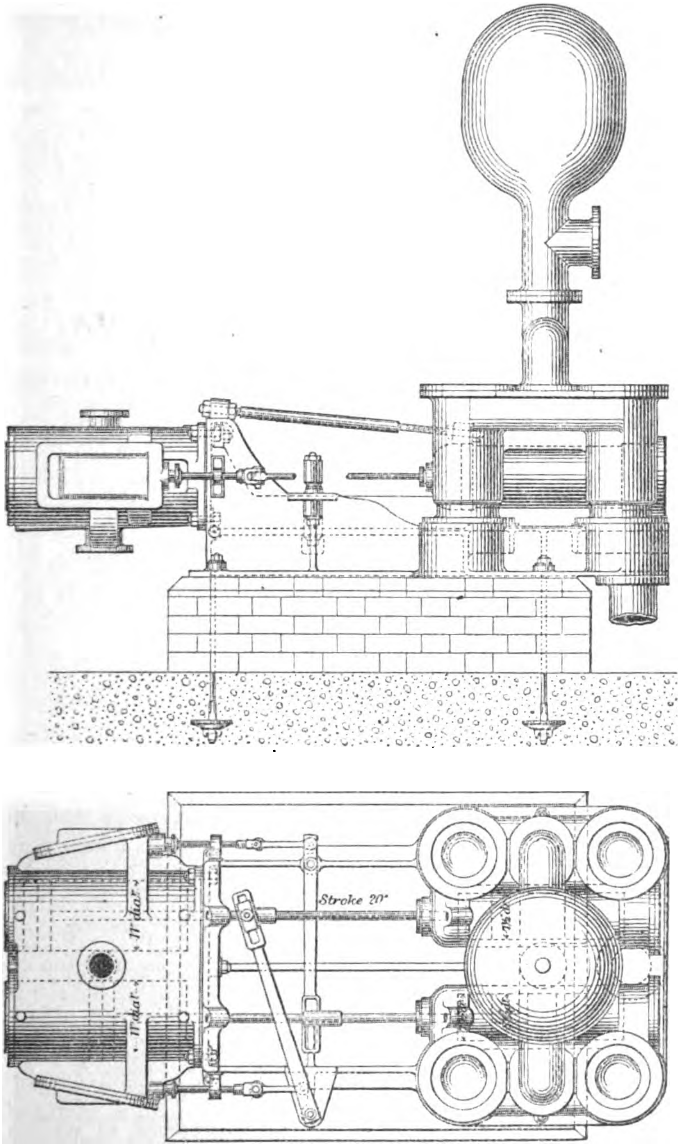
The floor of the engine-room is 27·2 feet above the Lower Hall, and is constructed of wrought-iron girders and Mallet plates, with concrete above them. A safe floor of similar but lighter construction is formed at a depth of 5·9 feet below the engine-room, and serves to give access to the waste-tank and many of the pipes, &c.

The plan of the engine-room at James Street is shown in Plate 5, Fig. 2. There are three boilers and three pairs of pumping-engines, arranged symmetrically, with steam-pipes so placed that any engine, boiler, or pipe can be shut off for repairs without stopping the rest. The boilers are of the return-tube type, each 6 feet 6 inches in diameter, 11 feet long, with a single flue 3·0 feet in diameter, and 3-inch tubes. They are constructed of mild-steel plates, and are loaded to 60 lbs. per square inch on the safety-valves. An iron flue over their front ends conveys their waste gases to the chimney in the corner of the engine-room.

The pumping-engines (Figs. 5) are of the duplex type, each with two steam-jacketed cylinders 11 inches in diameter, and 20 inches length of stroke, working direct off their piston-rods, two double-acting piston pumps 7½ inches in diameter, and 20 inches length of stroke. The slide-valve of each cylinder is worked by a lever from the piston-rod of the other, so that there are no dead centres, and they are so arranged that the pistons cannot strike the cylinder ends. So long as the gross pressure on each steam-piston exceeds the resistance against the pump-piston, due to the water-pressure against it, together with the friction of the working parts, these engines will keep working, pumping water from the waste tank into the system of pipes, which connects the top tank with the lifts. Any reduction of pressure in the pumps increases the speed; but immediately the above pressures and resistances are equalized, either by closing a valve on the delivery side of the

pumps, or in any other way, the engines stop "dead." They

Figs. 5.



start again, however, automatically at full speed, directly the

resistance to the pump action is relieved by opening the valve or otherwise, even though they may have been standing for hours in the interval. The valve or other resistance may be any distance, even miles off. As there is very little inertia in the working parts, the pressure against the pumps may be put on or taken off with the greatest rapidity without injury to anything.

Engines of this type have been used by Messrs. Easton and Anderson, MM. Inst. C.E., during the last twenty-five years for a great variety of purposes, such as waterworks with and without reservoirs, naphtha-pumping through long mains, working lifts, hydraulic presses, riveting-plant and gun-carriages, and as bilge-pumps and fire-engines on board ship. Their details and proportions have been considerably varied and improved by "natural selection," as a matter of course, in the interval, but the original principle remains.

Each set of engines at the Mersey works is proportioned to give a hydraulic pressure of about 1·6 time the boiler pressure when discharging 500 gallons per minute, rising to 1·9 time that pressure when working "dead slow." Pending the completion of the tower for receiving the top tank, the several lifts at James Street have been worked so far direct from these engines without any supply tank. The steam stop-valves on the engines are left wide open from morning to night, and their action is entirely controlled by the lift starting-valves. There is an air-vessel on each set of pumps, and a small one on each lift-valve, and these suffice to neutralize all irregularity of flow, so that no pulsations are noticeable in the lifts.

At Hamilton Street the tank and engines are now in full working order, and jointly supplying the lifts.

The normal duty of the engines is to automatically keep the top tank full, and to assist it to work any lift whose starting-valve is open for ascending. In case of an excessive load beyond the powers of the tank-pressure to deal with, the engines immediately take the entire duty of raising the lift so loaded.

The system of main-pipes and of change-valves between the tanks, pumps, and lifts, is shown in skeleton in Plate 5, Fig. 1. Three 7-inch mains descend from the tank-bottom to the several lifts, one to each.

Beneath the tank these pipes have sluice-cocks, A A A, and self-acting valves, B B B, which prevent flow through them towards the tank. Branches beyond these lead to ball-valves, C C C, for supplying the tank and shutting off the water when it is full.

In the engine-room multiple crosses are introduced in these mains, with branches to the pumps and connections between the several main pipes, and eleven 7-inch sluice-cocks so arranged that the engineer in charge can readily shut off any tank-main with the cocks D D D, or any pump with the cocks E E E, or any lift with the cocks F F F, still leaving everything else at work. With the cocks G G on the junction pipes he can cut off the connection between the mains, leaving each lift-system complete in itself, with its own tank main and pumping engine. In normal working, however, it is best to leave them and all the other cocks fully open, as each lift then gets the benefit of all three supply mains and all the pumping-engines which may be under steam at the time. There is no doubt that the concentration of these change cocks and mains, in accessible positions, and in a symmetrical and intelligible order, will prevent many mistakes on the part of the attendants.

The above pumping engines work at high pressure, and discharge their exhaust steam through a feed-water heater into the chimney. Donkey-engines of the small duplex type are to be added shortly, and short-stroke unbalanced ram-lifts are to be fixed on the platforms for raising luggage to the foot-bridges, from which the trolleys can be easily wheeled into the large lifts. Small hydraulic ash lifts for raising the ashes produced in the engine-room are also in contemplation. All will be worked from the same system of mains in the engine-room.

The office passenger-lift is of the type generally adopted by Messrs. Easton and Anderson, with a 7½-inch wrought-iron ram ⅜-inch thick, a forged-iron cross at its top end, a steel-plated cage with domed steel-plate roof, and a heavy chain and counterweight. The roof of this lift-cage will be serviceable for giving access to the pipes from the tank which pass down the lift-space beside it to the engine-room below.

General Remarks.

The lifts described in this Paper were designed by the Author and constructed by his firm, Messrs. Easton and Anderson, to meet the specified requirements of Sir James Brunlees and Sir Douglas Fox, the Engineers of the Mersey Railway, under whose supervision the whole of the works were carried out. The machinery was erected by Mr. C. R. May, Assoc. M. Inst. C.E., as Resident for the Contractors.

Each lift is very similar in construction to the large lift at the

Army and Navy Stores in Westminster, but about four times its capacity and power.

The number of lifts at each station, viz. three, was the suggestion of Mr. Francis Fox, after consideration of lift-practice on a smaller scale in the large hotels of the United States. If it had been convenient to put surface stations on each side of James Street and Hamilton Street, two separate lifts might have been carried down to each platform; but probably few passengers will object to walking upstairs to the foot-bridge level, and the station staff is certainly reduced by concentrating the lifts in one building. In some respects it would have been convenient if the three lifts could have been placed symmetrically side by side, but the sites of the stations did not lend themselves well to this arrangement.

Several considerations led to the adoption of low pressure instead of high pressure for working the lifts. A single direct-acting ram was from the first selected by the Author as the safest and best principle to adopt. The average passenger probably weighs less than 10 stones, or 140 lbs. Each lift was proportioned to raise a maximum load of one hundred passengers of about 150 lbs. weight, or 15,000 lbs., when working with the tank-pressure. A large cage was indispensable for so many, and they might crowd to one side, or at one end of it. With 660 lbs. hydraulic pressure per square inch, a 6-inch solid steel ram might be used to give the above lifting power; but a full load on one side of the cage would break such a ram at once transversely, and even as a central load the ram, considered as a column jointed at one end, would be extremely weak at the joints. The 18-inch ram has a margin of safety of about 30 as a column, and about 6·6 under transverse strain, with the full load concentrated at 5 feet from the centre of the cage, towards one side.

The 10,000-gallon supply tank at James Street gives an accumulator storage-power equal to twelve journeys; to give the same reserve power with a ram accumulator for working 6-inch high-pressure lifts would have necessitated a 30-inch ram, 36·7 feet length of stroke, and a load on it of 208 tons. No doubt Sir William Armstrong was right in adopting high pressures and accumulators for scattered duties, but for concentrated lift-service the present arrangement, which is very similar to that first adopted by Sir William Armstrong at the Grimsby Docks, has many advantages.

Great economy of power and freedom in working is obtained by the adoption of leathers instead of packings for the main ram-glands. So far not a single leather has required renewal, and the

Author thinks it probable, from similar experiences, that their average life will be about two years. Packings combined with high pressure are very liable to score the rams, and with careless attendants they entail enormous losses of power in friction, especially in low-pressure lifts.

The water is used over and over again with very slight waste, and getting greasy, much assists the lubrication of the rams, and makes the hand-starting valves work very easily. With fresh water every time, no doubt such large valves would work heavily. The valve faces are purposely made of dissimilar metals, as the Author has found great tendency to "seize" when flat surfaces of the same metal rub heavily on one another in clean water.

The internal cage-floor area is 322 square feet, or 3·22 square feet per passenger. On several occasions crowds of one hundred and forty passengers have travelled up in a cage, and once one hundred and seventy-one are said to have crowded into one, though strict orders are in force limiting the number to one hundred. Sir J. W. Bazalgette and Sir Frederick Bramwell once tested the density of a packed London crowd, and obtained a load of 1¼ cwt. per square foot, or one person of 10 stone per square foot. Thus the normal space allowed in these cages per passenger is 3·2 times that for a dense crowd.

Speed.—A convenient speed in these lifts is about 2 feet per second, corresponding to thirty-eight seconds per journey at James Street, and forty-four seconds at Hamilton Street. They are capable of working faster, and as a matter of fact often do so; but the Author does not think high speeds desirable, considering the great inertia of the moving loads, and the responsibilities involved. The total moving mass when a lift is fully loaded is nearly 30 tons. The V-shaped ports and the self-acting flap in the starting-valve make the starting and stopping extremely smooth and pleasant for the passengers.

Guides.—The Author always prefers sliding guides in preference to rollers, which almost invariably wear in flats, and are difficult to adjust and keep from grinding on their flanges.

The accident to a lift at the Grand Hotel in Paris led to many inventions for doing away with balancing chains, but, the Author thinks, without sufficient reason. The accident in question was due to defective construction, such as would never be tolerated in English practice. Hydraulic balancing leads to greater complication of parts, and leaves risks quite as great as those which are avoided. The chains in the present case, combined with the counterweights, serve a very important duty, as they almost

entirely relieve the ram of transverse strain, when a crowd is concentrated at the front or back of the cage, as the weights must be entirely supported by the tighter chains before any appreciable transverse strain can be communicated to the ram. In the Mersey lifts each chain weighs 13·3 lbs. per lineal foot, so that 2 lineal feet of all four chains just about balances the loss of pressure due to the ram rising 1 foot.

Attachments.—The Author assigns the utmost importance to the security of the attachments in lift-construction, especially those of the cage-frame to the ram, the chains to the frame and the counterweight, and the pins in the chain-pulleys. All these are specially guarded, and are easily accessible for inspection.

The platforms round the roofs of the cages give great facilities for the inspection of working parts, oiling and cleaning of guides and pulley-pins, and for adjusting the counterweights without risk to the attendants.

Tests.—The lifts were tested by General Hutchinson, R.E., on the 29th of December, 1885, with a load of about 19,000 lbs. dead weight in each. This load was shifted close to one side of the cage by his direction, and the lift (worked direct by the engines) raised it from the bottom to the top satisfactorily without the slightest appreciable racking of the cage or hard rubbing on the guides.

The total cost of the six lifts, with all their attendant machinery, was about £20,000.

The first cylinder was lowered into place at the end of August, 1885, and the lifts were officially tested and passed for work on the 29th of December, 1885.

The outline calculations for the balancing and variations of loads on the chief working parts are given in an Appendix.

The Paper is accompanied by several drawings, from which Plate 5 and the Figs. in the text have been prepared.

[APPENDIX.

APPENDIX.

CALCULATIONS for BALANCING, and DETERMINATION of VARYING LOADS and STRESSES on CHIEF WORKING PARTS.

—	James Street. Levels above datum.	Hamilton Street. Levels above datum.
	Feet.	Feet.
High-water level in tower tank	390·6	414·0
Bottom ditto	382·1	405·5
Average summit level of waste-pipes from lifts discharging into waste-tank	214·1	250·0
Bottom of waste-tank	205·3	241·0
Upper booking-hall floor	271·6	292·2
Lower hall floor	195·0	204·5
Station platform level	182·2	191·7
Engine-room floor	222·2	261·8
Bottom of boring	111·5	109·8
Ram-bottom at top of stroke	190·6	200·0
Ditto, ditto, at bottom of stroke	114·0	112·3

Stroke of lift in feet	76·6	87·7
Effective head of water available for working lifts from top tank	390·6 − 214·1 = 176·5 feet	414 − 250 = 164 feet
Corresponding pressure per sq. inch	76·4 lbs.	71 lbs.
Area of ram, bare 18 inches diameter	254 sq. inches	254 sq. inches.
Load which could be lifted in perfect frictionless lift infinitely slowly	19,405 lbs.	18,034 lbs.
Practical efficiency allowed for, considering that lift must be able to descend when empty	0·8	0·8
Effective lifting power on up stroke with this efficiency	15,524 lbs.	14,427 lbs.
Average difference between loads on cage and counterweight sides of chain pulleys, to produce motion upwards when cage is fully loaded, and pressure from top tank is on ram; and also to produce motion downwards when cage is empty and cylinder discharging into waste-tank; = half above difference, or 10 per cent. of effective load in perfect machine	$\frac{19{,}405 - 15{,}524}{2}$ = 1,940 lbs.	$\frac{18{,}034 - 14{,}427}{2}$ = 1,803 lbs.
Weight of water displaced by 1 foot length of ram	110 lbs. = 11 gals.	110 lbs. = 11 gals.
Ditto displaced in full stroke of ram	76·6 × 110 = 8,430 lbs.	87·7 × 110 = 9,650 lbs.
Weight of four $1\frac{1}{8}$-inch chains together, per foot	4 × 13·35 = 53·4 lbs.	53·4 lbs.
For perfect balance in all positions, weight of chains per foot should be	$\frac{110}{2}$ = 55 lbs.	55 lbs.

——	James Street.	Hamilton Street.
Pressure from supply-tank on ram-bottom, at bottom of stroke going up	390·6 – 114·0 = 276·6 feet = 119·8 lbs. sq. in. = 30,430 lbs.	414 – 112·3 = 301·7 feet = 130·6 lbs. sq. in. = 33,170 lbs.
Ditto at top, going up (= subtracting ram displacement from last) . .	22,000 lbs.	23,520
Ditto from waste-tank on ram-bottom, when at top of stroke and descending	214·1 – 190·6 = 23·5 feet = 10·2 lbs. sq. in. = 2,590 lbs.	250 – 200 = 50 feet = 21·6 lbs. sq. in. = 5,490 lbs.
Ditto at bottom, descending (add displacement to last)	11,020 lbs.	15,140 lbs.
Weights affecting Stresses.	Lbs.	Lbs.
Ram and centre bolt	9,470	10,730
Forged cross under cage floor. . .	2,400	2,400
2 girders under cage floor, rivets, &c.	3,600	3,600
Iron stirrups.	210	210
4 guide brackets	270	270
Woodwork in cage and seats . . .	13,100	13,100
Lamp, &c.	150	150
Total	29,200	30,460
Weight of Chains.		
Weight on cage side of pulleys at bottom of stroke	93·3 × 53·4 = 4,980	104·4 × 53·4 = 5,570
Ditto at top of stroke	890	890
Ditto on counterweight side at bottom of stroke	620	620
Ditto, ditto, at top of stroke . . .	4,710	5,310
To determine Weight of Counterweights.		
Put empty cage at top of stroke and descending very slowly. Then total load on cage side of pulleys—		
= ram, cross, cage, &c. as above . .	29,200	30,460
Chains on cage side	890	890
Total weight on that side . .	30,090	31,350
Deduct pressure on ram-bottom from head of water in waste-pipe as above	2,590	5,490
	27,500	25,860
Deduct weight of chains on counter-weight side at same time . . .	4,710	5,310
	22,790	20,550
Deduct allowance as above for friction and to produce motion . .	1,890	1,800
Then total counterweights = .	20,900	18,750

—	James Street.		Hamilton Street.	
	Lbs.		Lbs.	
Check at bottom of stroke, cage descending—				
Ram, cage, &c. as above	29,200		30,460	
Chains on cage side	4,980		5,570	
	34,180		36,030	
Deduct pressure on ram from head in waste-pipe	11,020		15,140	
	23,160		20,890	
Deduct weight of chains on counterweight side	620		620	
	22,540		20,270	
Deduct allowance as above for friction and to produce motion. . .	1,890		1,800	
	20,650		18,470	
N.B.—Differences in above estimates due to deficiency in weight of chains (= 3·2 lbs. per foot of stroke) . .	250		280	
Taking mean of above figures the counterweights on each side of lift should amount to	10,390		9,300	
Variation of pressure upwards at centre of cross due to pressure on ram bottom, less weight of ram, and say $\frac{1}{3}$ of friction allowance—				
Lift at bottom, fully loaded, rising slowly—				
Pressure on ram-bottom, as above .	30,430		33,170	
Less weight of ram and centre bolts, do.	9,470		10,730	
	20,960		22,440	
Less $\frac{1}{3}$ of friction allowance . . .	630	+20,330	600	+21,840
Lift at top, fully loaded, rising—				
Pressure on ram	22,000		23,520	
Less weight of ram, &c. + $\frac{1}{3}$ friction as above	10,100	+11,900	11,330	+12,190
Lift empty at top descending slowly—				
Pressure on ram-bottom	2,590		5,490	
Less weight of ram	9,470		10,730	
	−6,880		−5,240	
Add $\frac{1}{3}$ friction allowance	+ 630	− 6,250 in tension downwards.	+ 600	− 4,640
Lift empty at bottom, descending—				
Pressure on ram-bottom	11,020		15,140	
Less weight of ram, &c.	9,470		10,730	
	+1,550		4,410	
Add for friction.	+ 630	+ 2,180	+ 600	+ 5,010

—	James Street.		Hamilton Street.	
	Lbs.	Lbs.	Lbs.	Lbs.
Variation of shearing force at junction of each corner foot of cage-cross with floor-girder.				
Shearing force with lift at bottom, going up slowly loaded—				
Push on cross centre, as above . .	20,330		21,840	
Less weight of cross	2,400		2,400	
	17,930		19,440	
This divided by 4 for number of feet	= say	+ 4,480	say	+ 4,860
Shearing force at top, going up loaded, by similar calculations	=	+ 2,370		+ 2,450
Shearing force at top, descending empty	=	− 2,170		+ 2,610
Shearing force at bottom „ „		− 110		+ 660
Pull upwards by each chain on end of cage girder.				
Lift at bottom and rising—				
Load on weight side. ¼ counterweight	= 5,200		4,650	
Chain	= 160		160	
	5,360		4,810	
Less friction ¼ of 630	say 160		150	
	5,200		4,660	
Less long chain on cage side . . .	1,240		1,390	
		3,960		3,270
Ditto with lift at top and rising, similarly	=	6,000		5,610
Ditto ditto descending „		6,320		5,910
Ditto at bottom „ „		4,280		3,570
Load on each chain-pulley pin with cage at bottom ascending—				
Load on counterweight side of top pulley	5,360		4,810	
Ditto ditto cage side	5,200		4,660	
Weight of pulley . . . . say	800		800	
		11,360		10,270
Ditto with cage at top and ascending, similarly	=	13,400		12,610
Ditto ditto ditto, descending . . .		13,720		12,810
Ditto ditto, bottom „ . . .		11,680		10,570
Maximum load on each stirrup girder is with cage at top and descending—				
Load on 2 pulley-pins together . .	27,440		25,620	
Weight of 2 stirrups, and girder itself	1,330		1,330	
		28,770		26,950

	James Street.	Hamilton Street.
Maximum pull on chain on cage side of top pulley, with lift at top and descending	Lbs. 6,540	Lbs. 6,130
Proof test of chains which are of $1\frac{1}{8}$-inch iron	Tons. 15·12	Tons. 15·12
Maximum bending-moment on arm of cage cross at 12 inches from centre of ram	Lbs. Inches. 4,480 × 70 =313,600 inch-lbs.	Lbs. Inches. 4,860 × 70 =340,200 inch-lbs.
Section of arm at that point (steel forging)	15 inches deep 2 inches thick	Ins. Ins. 15 × 2
Probable margin of safety at that point, supposed to be its weakest section	14·3	13·2
Maximum bending-moment on ram, supposing full load concentrated at 60 inches to one side of centre of cage	15,000 × 60 = 900,000 inch-lbs.	..
Ultimate moment of resistance of 18-inch mild steel ram $\frac{5}{8}$-inch minimum thickness at screw threads. (Rankine, f = as per test 63,000 lbs. per square inch)	5,900,000 inch-lbs.	..
Margin of safety	6·6	..
Maximum load on top of ram as a strut at top of stroke (see thrust on cross-centre as above)	11,900 lbs.	12,190 lbs.
Ultimate strength of ram as a strut fixed at one end and jointed at the other, taking it as $\frac{5}{8}$-inch minimum thickness at screw threads, and only allowing mild steel same strengths as wrought-iron (Rankine)	370,000 lbs.	315,000 lbs.
Margin of safety	31	26

[Discussion.

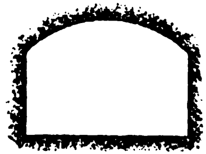
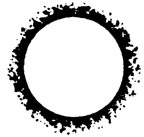
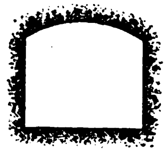
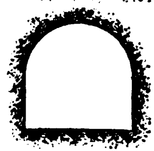
Discussion.

Mr. Fox. Mr. FRANCIS FOX said that the subject of his Paper was one full of novelty; the ventilation, lifts, pumping, locomotives, and other matters involving many new features. The problem to be solved by the Company's Engineers was how to compete satisfactorily with the excellent ferry-boats that traversed the Estuary of the Mersey. Celerity and comfort were the two things to be considered. Passengers from the heart of Liverpool to the heart of Birkenhead using the ferry-boats occupied a certain time, which the tunnel had now reduced by fully fifteen minutes each way. The trains ran from station to station in three and a half minutes, and, allowing one and a half minute for going down comfortably from the level of the street in the lifts, and getting into the train, and one and a half minute at the other end for getting out and going up into the street, the total time occupied from the heart of Liverpool to the heart of Birkenhead was six and a half minutes. One important feature, of course, was the ventilation. The Company had to compete with the ferry-boats which had the benefit of the pure breezes on the river; and it was therefore essential that special attention should be devoted to this subject. The figures given in the Paper showed an estimated total yield of the fans of 580,000 cubic feet of air per minute. Within the last few days preliminary experiments had been carried out, the results of which, as given in the annexed Table (p. 81), showed an increase to 651,420 cubic feet. It would be observed that there were some inequalities in the yields, and also in the velocities obtained; but that was due to certain circumstances which he need not then detail. The interesting feature was, that through the circular heading having an area of 41 square feet, and with a water gauge of 2·2 inches, the air attained a velocity nearly as high as 3,300 lineal feet per minute. It was thought that the cheapest and best way of ventilating the tunnel would be by mechanical means, and that the most expensive means would be to rely upon natural ventilation. He had omitted to state that the credit of the fans was due to Messrs. Walker Bros. of Wigan. He might also be permitted to bear his testimony to the energy, skill and constant attention which Messrs. Waddell and Sons had devoted to every detail.

Mr. Rich. Mr. W. E. RICH said that the Birkenhead Forge Company elected to make the cage-crosses of steel in preference to iron, as being by far the more trustworthy material for so complicated a

Mr. Fox.

MERSEY RAILWAY.—VENTILATING FANS. RESULTS OF EXPERIMENTS (FIGS. 8).

Fan at	Diameter of Fan in feet.	Width of Blade in feet.	Number of Revolutions per minute.	Area of Drift Way in square feet.	Water Gauge in inches.	Velocity of Air in feet per minute.	Volume of Air in cubic feet per minute.
Hamilton Street, Birkenhead	30 ×	10	47	113 	1·30	1,895	214,135
Shore Road, Birkenhead . .	40 ×	12	45	41 	2·50	3,288	134,685
James Street, Liverpool . .	40 ×	12	45	72 	2·45	2,465	178,880
James Street, Liverpool . .	30 ×	10	60	60 	2·30	2,062	123,720
						Total .	651,420

Mr. Rich. forging. In wrought iron, welds would have been necessary, and they were always objectionable in such large sections. A great deal of the shaping was done by the slotting-machine, as he believed was usual in some of the best forges of the day. He had sent to the forge to ask what was considered to be the strength of the steel in the finished forging, and the reply was that it was from 28 to 34 tons per square inch, with elongation 20 per cent.; the amount of carbon in the steel being about 0·23 per cent. His desire was to have everything as strong as possible in proportion to the weight, and he intended to have adopted teak for the floor joists of the cages; but on reference to the directors of the Starbuck Company, who constructed the ascending rooms or cages, they showed him some interesting experiments by Mr. Slater, of the Gloucester Wagon Works, upon the transverse strengths of various timbers, which proved pitch pine to be vastly stronger transversely than teak or oak, or any other wood ordinarily used. He had placed upon the table a section of the steel ram, and members could see where the weld was; also a section of the rail which was used for the guides; it was made with a V-shaped top flange, so that the guides could be adjusted upon it. In discussing the merits of the low-pressure system of hydraulics for sundry lift-duties such as those referred to, he by no means wished to speak against the system of high-pressure hydraulics for more scattered duties, or to detract from the credit due to Sir William Armstrong for introducing the pressure of 700 lbs. per square inch, which was now almost universal.

Mr. Eckersley. Mr. W. Eckersley asked Mr. Fox, what was the mode of proceeding in the construction of the tunnel under those parts of the river where the rock was sound, and where there was a moderately thick cover of rock? Mr. Fox had said that, in the portion of the tunnel where the old river-course was, the rock was excavated in lengths of 9 feet, which were heavily timbered; but what was the mode of dealing with other portions of the tunnel where the rock was good? Were the lengths much greater? and what timber was used? He would also like Mr. Fox to state what had been the cost of the rock-work and brick-work, particularly with reference to the excavation of the rock-work under the river-bed? Also what had been the cost of pumping during the construction of the tunnel, what percentage he thought it added to the various classes of work, and what was his estimate of the cost of pumping after the line was finished, and in course of working, and the consequent addition to the working expenses? Further, it would be interesting to know what the ventilating was likely to cost.

Mr. W. SHELFORD said that a somewhat critical examination of the cross-sections of the tunnel (Plate 3) had convinced him that there was a difference in the general cross-section of the tunnel on the Birkenhead side, as compared with the Liverpool side. It was not very great, but still it was important. On the Birkenhead side the top consisted of a semicircular arch, and on the Liverpool side that arch had been raised in the haunches, apparently to give more room for the rolling-stock. It seemed to him desirable to know which was the original section, and which was the amended and more recently approved form. He presumed both sections were not designed at the same time. If the Liverpool section was the first adopted, then it looked as if it had been necessary to strengthen the tunnel by altering the form somewhat on the Birkenhead side. He should think that more likely the converse was the case, and that the haunch on the Liverpool side was raised for the purpose of giving more room for the rolling-stock. Many years had passed since a discussion upon tunnels took place in the Institution, and it might be worth while to direct attention to the somewhat altered circumstances which had since arisen. When railways were first formed, he thought the general or the best practice was to make tall and narrow tunnels—tall for the purpose of allowing space for the smoke to accumulate and pass off, and narrow because the rolling-stock was narrower than it was now. Tunnels were now made wider and lower. There was first in 1837 the important Kilsby tunnel, on the London and Birmingham Railway, which was 23 feet 6 inches in height, and 24 feet wide. Then in 1860 there was the Sydenham tunnel, on the Chatham and Dover Railway. Both of those tunnels gave considerable trouble in their construction. The Sydenham tunnel was 21 feet high, and 24 feet in width. About that time many tunnels were made very similar to it in dimensions and form. The Mersey tunnel upon the Liverpool side was 26 feet wide and only 19 feet high; but it gave what the others did not, namely, the width of 25 feet, at a height of 10 feet 6 inches above the rails, which he thought the Board of Trade requirements now made necessary. The earlier practice was to make the tunnel an ellipse with its major axis vertical, the idea being that it would better sustain the top weight; but he believed experience in tunnelling (certainly his own experience) had shown that as much strength was wanted upon the sides as at the top; that the pressure was pretty uniform all round, and consequently that the elliptical section was very liable to give way. The Sydenham tunnel in 1860 was first constructed upon the elliptical section, and was Mr. Shelford.

Mr. Shelford. afterwards altered very considerably, in the manner described in a Paper by Mr. A. E. Baldwin.[1] A tunnel made two years later under his superintendence in the same hill, on the Crystal Palace High Level Railway, was of a semicircular section, which corresponded nearly with that of the Mersey tunnel. The effect of the change in the form was enormous—so much so that whereas with the former section ten rings of brick-work were crushed, the section with a semicircular arch stood well with six rings. The Sydenham tunnel was 2,200 yards in length, he considered that nearly one-half its cost would have been saved if the semicircular form had been adopted instead of the elliptical one. He thought this was important; but there was another point in connection with it which appeared to him to be worth thinking about, namely, whether there was really any necessity to leave a space above the trains for the accumulation of smoke. Those who were experienced in such matters knew that smoke clung to the roof of the tunnel; but judging from the modern practice he gathered that most engineers were of opinion that it was no longer necessary to leave a space for the accumulation of smoke. He presumed that Mr. Fox, Sir James Brunlees, and Sir Douglas Fox relied upon the artificial, mechanical ventilation from the outside: but he should be glad to know whether they thought it was necessary to make tunnels higher than the rolling-stock required, in order to allow more space in cases where mechanical ventilation was not used. He understood the verdict of Engineers to be against the practice.

Capt. Galton. Captain GALTON had listened with great attention to the part of Mr. Fox's Paper relating to ventilation; but it appeared to him that in an entirely new railway—especially a short line not exceeding a mile in length in which the trains were continually running from end to end only—it would be simpler to use the power of the train itself to ventilate the tunnel instead of adopting a system of mechanical fans. If the tunnel (reduced in height as suggested by Mr. Shelford) were divided by means of a diaphragm, each train would act as a piston to drive out the foul air before it and draw in the fresh air after it. He could not see why such a system could not be economically adopted instead of having a double line in one tunnel. The present process, as Mr. Fox had stated, was one of continually churning up the foul air which the trains created inside the tunnel. By using the tunnel as its own cylinder and piston, the

[1] Minutes of Proceedings Inst. C.E. vol. xlix. p. 232.

necessity of having ventilating fans and other arrangements would be avoided. Of course that could not be done in a tunnel beyond a certain length, or which was of old construction, or with mixed trains; but in an entirely new undertaking, for passenger traffic between two termini, it seemed a pity not to take advantage of the effect which the trains themselves produced. Capt. Galton.

Mr. W. B. LEWIS said he was present at the opening of the Mersey tunnel, and was delighted with the effect of the ventilation arrangements. He wished to ask whether Captain Galton's plan would not necessitate a wider tunnel (which would of course increase the expense), and whether there was any other tunnel so freely ventilated as the Mersey tunnel? In the case of the Metropolitan District Railway the openings were doubtless good and necessary, but he believed they had not been so successful as the plan adopted by Sir James Brunlees and Sir Douglas Fox. Mr. Shelford had omitted to refer to the material in which the tunnels he instanced were constructed. In 1849 Mr. Lewis was engaged upon a tunnel in clay. That tunnel, at that date, had a semicircular top, which it became necessary to raise a little, because notwithstanding the great pressure all round, the top weight was found to be the greatest; it was a troublesome place, where the timbers were broken from below as well as from above. In the case of the solid rock under the Mersey, simply a good form that would stand the hydrostatic pressure was required. A form approaching the circular would be the best. He believed that the Sydenham tunnel was made circular, not with a view to accommodate the smoke, nor from supposing that the smoke could be dealt with differently, but because the clay required it to be so made. He was sure that every one who visited the Mersey tunnel would see how excellent it was, and how carefully everything had been considered and carried out. Mr. Lewis.

Mr. W. SHELFORD wished to explain that the two tunnels to which he had specially referred were through the same hill—in London Clay. Mr. Shelford.

Sir FREDERICK BRAMWELL, President, said that Mr. Fox, having put up an additional diagram, wished to give some explanation. Sir F. Bramwell.

Mr. F. FOX observed that as some questions had been asked with reference to the ventilation, he exhibited a diagramatic sketch, which with a brief explanation would serve to render the subject much clearer. It must be taken purely as a diagram, and with that view he had kept the 40-feet fan and the 30-feet fan separate. As a matter of fact they were really in the same building. It was intended that the drainage-heading Mr. Fox.

Mr. Fox. should have been immediately under the tunnel for its whole length, but, owing to the rails having been lowered, it was absorbed into the tunnel and became the bottom heading for the tunnel proper. Consequently, it was necessary to have an additional heading for drainage purposes, and this was driven on one side and called the "Loop heading," and it was turned into the original drainage-heading so soon as the gradient of the tunnel allowed the junction to be effected. The "Loop heading" served both for drainage and ventilation. It was continued as a ventilation-heading up to the fans, and smoke-holes were provided between the tunnel and the ventilation-heading at stated intervals, three or four on each side of the centre of the river. The object of these smoke-holes was, that in the event of anything interfering with the draught owing to the open end of the tunnel (which was a matter of some difficulty), by opening or closing these doors there would be absolute control over the ventilation. The system, as explained in the Paper, was that the fresh air should enter at the station. The air then divided, one-half going one way, and one-half the other, so that the products of combustion were immediately swept into the tunnel, and the platforms were kept clear. The air travelled to the centre of the tunnel, and was drawn out through the ventilation-heading by the 40-feet fan. The 30-feet fan ventilated the land portions of the railway. He had doors placed between the two fans, so that in the event of anything going wrong, a most improbable occurrence, and one fan getting out of order, by throwing these doors open, the other fan could perform, to a modified extent, the work of both, and ventilate both sections of the tunnel. There was a small smoke-hole at each end of the top of the station arch which was in communication with the 30-feet fan, and, by opening a door by means of a chain, any foul air that happened to accumulate in the soffit of the arch could be removed. When a locomotive was standing at either end of the station its products of combustion, instead of fouling the air of the station, were immediately swept away by the 30-feet fan. He exhibited a photograph of the locomotive, of which Messrs. Beyer and Peacock were the builders—an excellent engine in every respect—and he wished to take that opportunity of stating how generously they had acted throughout the whole proceedings. There was a great deal of novelty about the engine, and any little trifling matter that wanted putting to rights they immediately attended to. He desired to say a word about the air-pipe for letting air escape from between the two wedging cribs in the shaft-tubbing. He did not attempt to explain why it was necessary, but he had a letter

from Mr. A. L. Steavenson, the well-known mining engineer of Durham, on the subject. He said that evidence was given before the Royal Commission on Mines, that blowers of gas had been met with in working collieries at a pressure of 400 lbs. per square inch, and the reason why the tubbing was so often cracked and broken—it could not be broken by the mere hydrostatic head—was due to the gas being penned up behind the tubbing under some of these tremendous pressures. Mr. Fox.

Mr. J. W. Barry observed that considering the monumental nature of this work, and its possible future as a means of communication between Lancashire and Cheshire, he regretted that the gradients were of necessity so steep, because in future this would no doubt become a serious matter in working expenses. But apart from that, and regarding the railway as a means of communication for the populations of the two great towns on opposite sides of the river, he was struck with what he foresaw would be the very serious annual costs compared with those of other passenger lines, such as those in the metropolis. These annual costs were divided into the cost of pumping the water, the cost of the ventilation, and the cost of the lifts; and in considering questions which might come before many engineers as to the advisability of recommending either a tunnel or a bridge for crossing a river, these points should not be lost sight of. He hoped the Author would state the annual cost of pumping, of ventilation, and of working the lifts. He had a great deal to do with railways which carried the population of London at remarkably low fares, the capital cost of which lines was not very seriously different per mile to the cost of this undertaking. He knew there how serious a matter it was to be saddled with annual outgoings other than ordinary locomotive- and traffic-expenses. On the Metropolitan District Railway there were some expenses in pumping, but they were very small indeed as compared with the similar expenses of the Mersey tunnel. Perhaps the Author would be kind enough to mention the quantity and the quality of the water raised, and the pressure brought upon the brickwork if the pumps were stopped. He had some little knowledge of the pressure which had been experienced in the Severn tunnel, and it would be interesting to know whether any registration of the pressure due to the water had been arrived at in the Mersey tunnel. With regard to ventilation, no one who had seen the ingenious way in which it was managed for the Mersey tunnel could help being struck with the ability with which it had been grappled with. On the other hand he was bound to take exception to the state- Mr. Barry.

Mr. Barry. ment by the Author, that on the Metropolitan District Railway the holes cut in the roof of the tunnel communicating with the outer air were comparatively ineffective; and that though the products of combustion were to some extent expelled and fresh air was drawn in, yet in the absence of a complete system of mechanical ventilation the result could not be satisfactory. He was obliged rather to challenge that statement because some misapprehension had evidently crept into the mind of Mr. Fox and of other persons upon that point. In the case of the ten ventilators of the Metropolitan District Railway, there was a total in-draught of 392,000 cubic feet of fresh air, and an expulsion of 432,000 cubic feet of foul air per train, giving an average of 40,000 cubic feet per ventilator taking expulsion and in-draught only. He agreed with Mr. Fox that if by ventilation of any kind

METROPOLITAN DISTRICT RAILWAY VENTILATORS.

Summary of in- and out-draught of air per train.

Ventilation.	In-draught in Cubic Feet.	Out-draught in Cubic Feet.
No. 1	43,538	29,235
„ 2	25,263	19,550
„ 3	39,325	26,560
„ 4	67,037	35,200
„ 5	41,990	33,310
„ 6	64,050	84,017
„ 7	37,050	29,390
„ 8	44,034	57,761
„ 9	21,835	17,320
„ 10	8,222	100,030
Total	392,344	432,373

the results were from about 20 to 22 parts of carbonic acid and sulphurous acid gas in 10,000 parts of air there would be a very fair amount of purity, and no great cause of complaint. A calculation of the area of a cross-section of tunnel, and of the length of the tunnels between the District Railway ventilators, would show that taking the out-draught or in-draught of air only, and taking the tunnel-mouths into account on each side of the ventilators, the air was changed about every $4\frac{1}{8}$ trains that passed. Each train gave out per foot of travel about 5 parts of carbonic acid and sulphurous acid gas in 10,000 parts of the area of the cross-section of this tunnel. If 5 was multiplied by $4\frac{1}{8}$ the result would be 21 parts in 10,000 of the impurities due to the passage of trains on the District Railway. That was about the standard

of purity reached by ventilators in the Mersey tunnel, and it was quite good enough, although he should not be sorry to see it a little better. By careful chemical analysis of the air in the Metropolitan District Railway tunnels, it was found that after the opening of the new ventilators the impurities were about 21 in 10,000, which agreed with the other calculation. Before the ventilators were made the impurities were found to be about 56 parts in 10,000. The result was that instead of the District Railway ventilators being a failure, or a comparative failure, almost precisely the same degree of purity was obtained as by the ventilating fans on the Mersey Railway. But there was one great advantage about the ventilators on the District Railway, namely, that the motive power of the trains was utilized for effecting the ventilation, and the more trains were run the more power was brought in to carry on the ventilation. He did not mean to put it so highly as to say that if the number of trains was doubled there would be an equal amount of purity, because the fouling power would increase at a larger rate than the expulsion or in-draught of fresh air; but that amount of power was obtained merely from the passage of trains, and to some extent in relief of the passage of trains, because owing to letting air out of the ventilators the resistance of the air to the passage of the trains was less than if there were no ventilators in the roof. He thought therefore that some qualification was required of the statement in the Paper, that without mechanical ventilation things could not be satisfactory. The District Railway ventilators were very satisfactory from a ventilating point of view, and the air which issued from the ventilators was by no means foul, seeing that it was only 21 parts of foul mixture in 10,000. The air was in fact as good as on the Mersey Railway, which had been described as leaving little to be desired. He did not compare the Metropolitan Railway with the Metropolitan District Railway, because, owing to circumstances, the Metropolitan was not so well off in having ventilating spaces as the Metropolitan District, and he confined his remarks entirely to the District line. There had been a considerable amount of opposition to these ventilators, and a great many objections had been taken to them. It was said not only that they would be inefficient but also that they would destroy the foliage of the trees, that nothing could grow near them, and that they would be most offensive to passers by. As a matter of fact, all these things had turned out to be entirely illusory; no plants could grow better than those that grew round the ventilators on the Thames Embankment, and the air was Mr. Barry.

Mr. Barry. so comparatively pure, the impurity being reduced as it was to 21 parts in 10,000, that there was little or no smell. Captain Douglas Galton seemed to think that a tunnel of the length of the Mersey tunnel could be ventilated by dividing it into two tunnels and trusting to the action of the trains, but Mr. Barry did not agree with that view. A short single-line tunnel would no doubt be able to ventilate itself by the action of the train pushing or pulling the air in, but the experience acquired on the Underground Railway of fans was this, that any system of ventilation of long tunnels was liable to be upset by a strong wind, which appeared to render almost nugatory the action of a fan in one direction. The same result would follow if it were attempted to rely on the piston action of the train in a long tunnel, but the action of the trains was quite satisfactory in short tunnels or in the lengths between the various ventilating holes. As far as his experience went, the difficulty belonging to all mechanical means of ventilation of a tunnel, where the ends were open, that the whole system became liable to be upset by strong winds, could not be obviated. That difficulty did not so much occur in a railway so far underground as the Mersey Railway, but for one near the surface these effects were most perceptible, and if instead of a large tunnel for a double line of rails there was a tunnel for a single line, the effect of the wind, if blowing against the passage of the train, would be most pronounced. He had no doubt that in a long single-line tunnel, heavily worked, which was dependent merely upon the action of the train in it, the air would be found to be so foul at times as to be almost insupportable. That had been found by experience of single-line tunnels in many parts of the country; in some, under certain conditions of wind, the air was very pure indeed, but in other cases it was very bad indeed; and he recollected travelling in a single-line tunnel in France, where the engine-driver was found in a fainting fit from the bad air on arriving at the end of the tunnel, and the stoker was very nearly in the same condition. Returning, however, to the subject of the Paper, his experience of railways, which carried passengers at a very cheap rate, led him to believe that the annual outgoings would be serious in the Mersey tunnel. It was a very difficult matter in London to carry the travelling public at a profit when merely paying locomotive and traffic expenses. The other fixed costs at Liverpool must be serious, and further included the costs of the lifts. Every man who was brought to a station in London found his way in and out, on his legs; but in this case the passengers had to be raised or lowered by hydraulic lifts. These

matters were, however, incident to the position, and he did not wish to say more in the way of criticism. The work was a very difficult one, but the difficulties had been met in the most able way, and he congratulated the engineers who had carried out the work so successfully. Mr. Barry.

Mr. B. BAKER said a few evenings ago he had to admit that English bridge-builders had been rather worsted in an international competition about an important bridge. He was glad to claim that to-night they had got the best of it, for the Mersey tunnel was really the first important subaqueous tunnel that had ever been opened for public traffic. The Americans began two rather important tunnels, one under the Hudson River, and one at Detroit, and in both cases they had to abandon them, and they remained now partially constructed tunnels. He was certain that the Paper would be read with great interest by American and Continental engineers as the first example of an important tunnel under water. It was specially interesting to him, because the execution of the work solved a great many conundrums to which he had to address himself some years ago, in considering with Sir John Fowler another tunnel under the Mersey. With steel plates at £6 a ton it was very natural to consider the practicability of a bridge before accepting the unknown contingencies of a tunnel, but at the beginning of the century their predecessors in engineering adopted the reverse course, and though timorous as regarded large bridges they were really far less nervous about undertaking subaqueous tunnels than engineers of this generation. He had seen at Edinburgh, some two or three years ago, an engraving, with a printed description and estimate, dated 1803, of a proposed tunnel under the Forth. There were two tunnels 15 feet wide; the estimates were carried out in great detail, and by practical miners, who were prepared to execute those tunnels for £30 a yard. They did not expect to find much water, as a few miles up the Forth, at Bowness, a heading had been driven for more than a mile under the Forth, and at Whitehaven a heading had been driven under the sea for about ½ mile. In both cases they had the same experience that Mr. Fox had at the Mersey, and Sir John Hawkshaw had at the Severn; namely, that there was less water under the sea than under the land portion of the work. He thought that might be taken as being practically proved to be generally so in rocky strata, and the fact had an important bearing upon any future contemplated submarine tunnel, such as a Channel tunnel, or anything on a bigger scale—a tunnel to Ireland perhaps. One of the most interesting Mr. Baker.

Mr. Baker. of the conundrums which had puzzled him some years ago as to the Mersey tunnel, but which had now been solved, was the quantity of water to be pumped. Mr. Fox having given the actual quantities, he turned up his own figures with some curiosity, to see what he said about it fifteen years ago, and found that he had had a sanguine fit upon him, and also a despondent one, and the estimates varied correspondingly. Upon a sanguine view of the possibilities, he had estimated the quantity at 8,300 gallons per minute. Mr. Fox said between 7,000 and 8,000 was what it was thought would be permanently pumped, and plant had been laid down for pumping 18,700. When he was despondent, and assumed that the wettest piece of rock from which he had obtained data would extend right across the river, his figures came up to 36,700, which he held would not prevent the successful completion, though it would necessitate very powerful pumping machinery. The more sanguine of his associates considered that 4,000 gallons a minute would be the quantity, and finally the promoters went to Parliament saying that they expected 4,000, and would provide machinery for 8,000 gallons. If they had adopted the ordinary British jury plan, and taken a mean of the numerous estimates of promoters and opponents, it would have come out very nearly the actual figures given by Mr. Fox. Something had been said about the cost. The estimated parliamentary cost ranged from £133 a yard up to £400. Mr. Fox did not give the actual cost. It would not have been possible, perhaps, for him to do it, because so many items were included that it would be very often more misleading than saying nothing at all, and he should not be surprised if Mr. Fox elected to say nothing about the cost per yard. Then as to the work of ventilation. That was a very interesting subject to which he had given much consideration. The ventilation required was dependent upon the amount of fouling which the air underwent, and that was largely dependent upon the gradients. In this case the gradients between the stations at Hamilton Square and James Street were extremely favourable for working with a small expenditure of fuel, and therefore favourable for ventilation also. It would be entirely wrong to suppose that the fouling of the air with such dipping gradients need at all approach that on the Metropolitan Railway. There could be nothing better than the dipping gradients between stations, because then the gradients did a good deal of the work of the engines. Thus the falling gradient was equivalent to a heavy tractive force of the engines, and got them up to a high velocity; and ascending the gradient on the other side, pulled up the train, without much

use of the brakes. He considered the Mersey tunnel an extremely favourable line to work, as regarded the portion between Hamilton Square and James Street. Some years ago he made some careful experiments on the working of the Underground Railway engines, noting exactly what became of the power of the engines, following up, as it were, the expenditure of the different units of heat as they went round the varying gradients from Moorgate Street to the Mansion House. He found that on a level line, with ½-mile stops, and 36 lbs. of fuel per train-mile burnt by the engine, about 15 lbs. were utilized in overcoming the frictional resistance, and 21 lbs., or over 60 per cent. of the whole, were expended in getting up the speed, and by the brakes in pulling up. In this case, of course, most of the latter expenditure would be obviated. There was a smart falling gradient to get up speed, and a rising gradient to pull up the train, so he thought the portion of the line between these two stations could be worked with certainly one-half the combustion of fuel, and therefore one-half the fouling of the air, that was experienced in the ordinary ½-mile stoppages of the Metropolitan. He had found that with a "hog-backed" gradient of 1 in 100, and with the same expenditure of fuel as on the level, the speed fell off 10 per cent.; but on a dipping gradient it was increased 50 per cent., the stations being ½-mile apart. It was rather singular, but in 1833 some ingenious man had made a model of a little spring locomotive, and a length of railway like this with dipping gradients, and by experiment he found that, as compared with the level line, the little model train traversed the distance between the two stations in two-thirds of the time; that was, he got 50 per cent. increase of speed with the same power, or exactly the same as subsequent experience on a large scale had shown to be the case. It made such an impression upon the public, that a body of the shareholders of the London and Birmingham Railway memorialized the Directors to stop the construction of the line, and to proceed with the Liverpool and Birmingham Railway upon this plan of dipping gradients. Of course the fallacy was that there was no advantage in running down and up again, unless there was a station at each end, at which it was wanted to pull up. In the case of the Mersey Tunnel there was a station at each end, and in his opinion the gradients between Hamilton Square and James Street, though they appeared at first glance severe, were preferable even to a level line. Mr. Fox gave an estimate of the quantity of noxious gas put into the tunnel, but there need not be so much coal burnt in the tunnel, between the two stations, as he had cal-

Mr. Baker.

Mr. Baker. culated. On the other hand, of course every one would understand noxious gases did not mean what might be called the smoke coming out of the funnel, which would be ten times as much as Mr. Fox's figures, which referred, no doubt, to carbonic acid gas and sulphurous acid gas. The possible physical difficulties of a line like the Mersey railway were very great, and no doubt delayed the construction of the tunnel for fifty years. A tunnel under the Mersey was spoken of at the time that the Thames tunnel was under construction, and it was said that it would have been built if it had not been for the great trouble experienced in the Thames tunnel. The periodicals of fifty years ago made frequent references to the proposed tunnel under the Mersey. It was extremely difficult, apart from physical considerations, to carry out a work of that kind, unless there was some powerful railway company or public body to support the scheme. In the case of the Severn tunnel there was the Great Western Railway Company, but there was no powerful railway company behind the back of the Mersey tunnel. The greatest credit was therefore due to everybody concerned; not merely the engineers, but to the financial people and others, who had made this long-discussed project a practical fact of which all engineers might be proud.

Mr. Ward. Mr. Henry Ward said mention had been made of the cost of electric lighting, as against the cost of gas-lighting. In an institution with which he was connected tenders were lately received for both systems of lighting. The tender for gas was £1,200, and that for electric light, by the incandescent system, £2,500, but that £2,500 did not include the buildings. Nevertheless, it bore a very favourable comparison with the 5 to 1 ratio which the Author gave as being the ratio of the cost of electric light to gas. With reference to ventilation, it seemed to him that at best this tunnel was only ventilated by openings, something like ½ mile apart. When mechanical ventilation was used, he could not see why a more perfect system should not be adopted. Mr. Shelford had spoken of the section of a tunnel made in 1837 as having a very high section, probably high in order to allow space above the trains for the collection of bad gases. He could not see why, in a tunnel of that kind, where mechanical ventilation was used, an iron tube should not be put along the centre of the tunnel overhead, inside above the centre of the 6-foot way. It would be clear of the trains, and by frequent openings the bad gases could be extracted as they were formed. That had many advantages, in that the gases would be hot just as they were discharged from the locomotive, instead of, as at present, having to travel for, perhaps,

½ mile in the tunnel, being mixed up with pure air, and so cooled and very possibly allowed to sink to the bottom of the tunnel. With reference to Mr. Rich's Paper, it seemed that the working expenses on the railway were very heavy, and he wished to draw attention to the use of the uneconomical pumps to work the accumulators. He was surprised that neither a compound engine had been used for the work, nor a simple engine, capable of using the steam expansively. These duplex pumps had to work against a fixed head of water; it was therefore evident that there could be practically no expansion of steam; the steam must be admitted in each case up to the end of the stroke, or very nearly so. That could not be at all economical, and with six pairs of pumps working continuously, the cost of coal for the lifts would be double or treble what it might be, and the total amount must be serious. Another weak point about the pumps was the fact that, in common with all other duplex pumps, neither cylinder had any control over its own valve. One valve was thrown over by the piston of the other cylinder, no matter where its own piston might be. The result was that the length of stroke could never be very certain. There could be nothing like a pump controlled by a crank for certainty in the length of the stroke. In all pumps of the simple reciprocating character the length of the stroke depended also on the speed at which they worked. At high speeds the stroke was always a little longer than at low speeds, owing to the momentum acquired by the moving parts. Two or three suggestions had been made that the cost of certain parts of the work should be given. That really would be most helpful, especially to those who were connected with contractors: a statement of the cost per cubic yard of the rock excavation, the cost of pumping, or the average cost of pumping per cubic yard would be an immense help to many engineers. Mr. Ward.

Mr. James N. Shoolbred said his long residence in Liverpool, particularly at the time when the late Sir Charles Fox obtained the sanction of Parliament to this undertaking, had led him to take considerable interest in it, and he had followed it with much attention. He thought, in the first place, the engineers and those connected with the railway must be congratulated on the nature of the bed of the river, as it had turned out. Only a single fault had been encountered instead of the numerous ones which had been predicted in consequence of the broken condition of the sand-stone rock in the foundations of the Northern Docks in Liverpool. A very interesting feature, geologically, in the bed of the river was the large bed of boulder clay between the Liver- Mr. Shoolbred.

Mr. Shoolbred. pool side and the centre of the river. It was stated to have been originally the site of an old pre-glacial bed of the river by Mr. T. Mellard Reade, Assoc. M. Inst. C.E., who predicted its being found there, basing his conclusion on the fact of having discovered traces of the same pre-glacial bed higher up the river at Widnes, and again below at Runcorn. His prediction, made long before the tunnel operations, had been completely verified by facts. With regard to the bed of the river, it was a matter of some interest, as showing the porous nature of the rock, that the quantity of water pumped varied sensibly with the head of water according to the state of the tide, and also the amplitude of the tides. From information kindly furnished him while examining some of the pumping machinery, he calculated that, at neap-tides, about 3¾ million gallons of drainage-water had to be dealt with during the whole twelve-hours' tide. Of course a large portion of that water was land-water, as probably it was drier under the river than elsewhere. In high spring-tides this quantity came up to about 4 million gallons; the difference, therefore, between low and high tides was a little over ¼ million gallons. The ventilation arrangements, which he had also examined, seemed very satisfactory. The subways that were spoken of, as having been erected lately at Liverpool and Birkenhead, had made a very material difference in the access of fresh air. They acted as inlets, and assisted materially in keeping the stations clear. Of course, those circumstances of ventilation, as had been remarked, were very much disturbed at an open end, particularly at Hamilton Square—the only open end at present—when the wind blew in certain directions. The lighting arrangements by gas, as carried out by Mr. Sugg, were satisfactory. The gas itself sustained no material loss of pressure at that low depth, only about 1 inch; but this might be accounted for by the fact that, both on the Liverpool and the Birkenhead side, it was supplied direct from the gasholder, and, therefore, the loss due to a long circuit through the mains was avoided. As Mr. Fox had conferred with him as to the possibility of lighting the stations, &c., by electric light, he felt bound to take exception to the statements made in the Paper, or rather to the inference which might be drawn from them, which made it appear as if electric light was very expensive as compared with gas. He knew that in contemplating electricity for that particular place great precautions were required, and naturally so, to prevent any extinction taking place, and therefore the installation would have been of an exceptionally expensive character. It was not fair to compare an installation where two

hundred lights and a special generating station were required, with a large commercial undertaking supplying, on the Liverpool side, something like three million lights, and needing no special arrangements other than to carry the gas direct from the ordinary producers into the tunnel. Instead of lighting by electricity under those circumstances appearing so much more expensive, he would assert, if a similar installation of gas were laid down for that small requirement, most unhesitatingly, and on the authority of gas engineers of considerable experience, that the gas would be more expensive to lay down, and also to work afterwards. With regard to the effect that the Mersey Railway had upon the traffic between the two towns, the facilities given by the railway for getting from one town to the centre of the other, without the trouble of going down the river, were telling very largely, and people were availing themselves of them. He understood that the effect of the competition was very much to the detriment of the steam-boat traffic. Mr. Shoolbred.

Mr. E. B. Ellington wished to say a few words on Mr. Rich's Paper. The lifts therein described were the first that had been used for dealing with large railway traffic. They were likely to form a start to a new field in the use of lifts. In many other cases similar lifts would be needed, and it would be worth while to inquire, therefore, how far the system which Mr. Rich had adopted was the best with regard to safety, to general efficiency, and to economy in working. It was certain that the results obtained by Mr. Rich would be the best that could be had by the system adopted. But he submitted that it was not possible to obtain so good a result with lifts working with low-pressure as it would be if they were worked at a considerably higher pressure. He could not think that the reasons which had been assigned for the adoption of low-pressure in this case were conclusive. He regretted that the full particulars had not been given as to the tests made with this machinery, for it was somewhat difficult to compare the results obtained with what might be expected from high-pressure, without those details. It was of very little value to have a statement made that "the average journey is accomplished in from thirty to forty seconds, and the three lifts, working simultaneously, are capable of raising a heavy train load of three hundred passengers to the surface in about a minute." Was it intended to convey the impression that thirty seconds was the maximum speed, or were greater speeds obtained, for the question of speed was a very important one? The conditions under which these lifts had to work seemed to be eminently Mr. Ellington.

Mr. Ellington. adapted for high speeds. They had to rise a considerable height without any intermediate stops: and certainly everything which could reduce the time in the transit of passengers from one side of the river to the other was a decided advantage. He should also like to know whether the speed of from thirty to forty seconds was obtained with a full load of passengers, because if the maximum speed was thirty seconds with only two or three passengers in the cage, it was manifest that a much reduced speed would be obtained with a full load. His own view was that it was impossible with these low pressures to obtain a quick working speed with a direct-acting ram constructed as described. Mr. Rich had given the calculations upon which the lifts were constructed; but accepting the particulars he thought that the efficiency there stated could hardly be realized in practice with a full load of passengers. The size of ram adopted, 18 inches in diameter, with the height of lift of 87 feet, rising in thirty seconds, would involve a flow of water of 1,916 gallons a minute during the ascent of the lift, and as that quantity was supplied through the 7-inch pipe, the speed of the water in the pipe would be 1,150 feet per minute. It was true that when all the valves were open, and only one lift was working, the velocity of water in the three pipes would be reduced to one-third; but that showed the importance of having the exact data in order to compare the efficiency of these machines. In fact, Mr. Rich stated that one pipe was provided for each machine, and that there might be two or three—he supposed ordinarily not more than two—travelling at the same time. At any rate there would be two machines travelling at the same time. Comparing the quantity of water used at high-pressure, 700 or 800 lbs. per square inch, as against 76 in the case of the Hamilton Square lifts, it would be seen the quantity of water would be only one-tenth, and it was obvious that the friction from the water in such a case would be very much less, and to that degree there would be greater economy. But that was not the only point in dealing with these ram-lifts. The speed of the motion of the ram lifting 90 feet in thirty seconds was very considerable, and at starting the whole of the length of the ram, 90 feet, was immersed in the water of the lift cylinder. The water had also to pass down from the entering pipe at the top to the bottom of the ram, so that there was a double speed of water passing the ram, and the friction of the water at that speed was considerable. There again there was loss of power, and this loss of power necessitated, for the economical working of the lift, the reduction of the ram to the smallest size compatible with safety. Was it necessary to use a ram of

such a diameter as 18 inches? He could not follow the arguments Mr. Ellington. which had been adduced to show it was necessary. Mr. Rich had stated that a 6-inch ram would be sufficient to carry the direct load, but that it would be very weak under a transverse strain. Obviously there was some mistake here, not with reference to the particular design which had been adopted for these lifts, but to the general principle upon which such lifts should be constructed. There should be surely no possibility under the ordinary conditions of working, or under any working at all, of a transverse strain coming upon the ram of a lift; and later on in the Paper Mr. Rich said that his method of construction did remove the transverse strain in consequence of the chains and counterbalance weight, which kept the ram and the cage in a perpendicular position. If Mr. Rich's design was examined, it would be seen that there was very little guiding at the guides. The length of the arm of the guide was a very small fraction of the width of the cage, and he would submit that in that particular design, the guides acted more to prevent the twisting of the cage than to keep the ram itself in the vertical position, and to ensure the strain passing through its centre. If the cage was thoroughly well guided, how could any transverse strain come upon the ram? but even if that transverse strain were to be taken into account, a ram about 9 inches in diameter, but solid, would be equally as strong as the 18-inch ram used by Mr. Rich. The use of a ram of 9 inches would very much diminish the friction, and a much higher pressure could be employed, leading to greater economical results. He thought it might be laid down as a rule, in all cases where hydraulic pressure was employed, that it was desirable to use the highest pressure that the circumstances of the case admitted of. There did not appear to be anything in the case of the Mersey tunnel lifts which should have led to the adoption of such a low pressure of water, especially considering the great cost which had to be incurred in order to produce that pressure. The large towers, 120 feet high, with tanks on the top weighing 50 tons, were surely a more objectionable feature than an accumulator weighing 100 tons in the basement; Mr. Rich mentioned 200 tons—a most extravagant estimate. Merely as a matter of expense and strain, there did not seem to be any advantage in putting 50 tons on the top of a tower 120 feet high in order to save 100 tons down below; and which could be very much reduced without sacrificing efficiency. As Mr. Rich had spoken on the sacrifice of safety in doing away with counterbalance chains and weights, he should like to say a word or two upon that point,

Mr. Ellington. because the counterbalance chains and weights in a ram lift very much altered the character of the lift. To a large extent it became a suspended lift, and the water-pressure upon the ram simply balanced a certain quantity of weight of the ram and cage, and the whole lift of the load was done by gravity acting upon the counterbalance weights. A large ram necessitated the use of very heavy and large chains in order to counterbalance the varying displacement of the ram. The use of large chains was another impediment in the way of a high speed in working the lift, because it produced a rough unpleasant motion in running machines at high speed, and doubled the weight of the moving parts. He noticed from the calculation that Mr. Rich considered it necessary to balance the whole of the displacement. He had not found that to be the case; in fact, he had found when a ram-lift was worked at high speed, that while it was desirable in point of economy to balance a portion of the displacement the difference in the friction of the ram immersed in the cylinder—the friction of the water—and during the latter part of the stroke the friction in air was sufficient to balance a considerable amount of that displacement. Of course, though this apparently eliminated the effect of the loss by displacement, the loss itself in the economy of the lift remained, and that loss increased with the size of the ram used. With these long ram-lifts there was very great difficulty in dealing with the problems, and it might in some cases be necessary to use a certain amount of counterbalance weight and chains or wire ropes. The only way in which they could be used to secure safety and efficiency in working was for balancing that portion of the displacement which was necessary to be balanced, while the lifting power of the machine should be always accomplished by the hydraulic pressure, that was, the ram when used should be always in compression and never hanging. Mr. Rich had referred to the hydraulic balancing which Mr. Ellington had introduced of late, and especially as to its being the intention of that arrangement to get rid of the weights and chains to prevent accident. It was in his opinion much safer to do without chains or wire ropes where possible, but that was not the whole intention; the further intention was to devise a system which would enable a ram to be used of any size required for strength without reference to the working pressure employed, and that had been accomplished. There was one other argument which he would use in reference to high pressure as against low pressure, and that was the public distribution of hydraulic power, which had been in successful operation on a large scale in London for the

last three years, and which was spreading to other towns. In many instances the supply of power from the public mains had resulted in an economy to the consumer over the cost of erecting and working private plant upon the different premises. With a view to the full advantage of this public supply of power being obtained, it was desirable that for all private hydraulic plant erected hereafter, some standard of pressure should be adopted. That standard had practically been fixed by Sir William Armstrong through his practice over the last thirty years. He began with low pressure and abandoned it for high pressure. It was extremely inconvenient to have so many what might be termed breaks of gauge in the different pressures employed by different people with their own private plant; and when the question arose of reaping economy from the public supply, the differences in pressure introduced a considerable element of cost and difficulty into the process. That would be an additional reason why high pressure should be employed in cases such as the Mersey tunnel. He, in conjunction with Mr. Woodall, was about to put down a system of pipes in Liverpool on the same system as that at work in London. He should much like to know whether it was advisable to adopt a working pressure of 700 to 800 lbs. per square inch. If so he failed to see any validity in the argument derived from concentrated duties on which Mr. Rich relied in support of his selection of low-pressure hydraulic machinery. Mr. Ellington.

Mr. W. A. Gibson proposed to confine his remarks to the Paper of Mr. Rich upon the "Hydraulic Passenger Lifts at the Underground Stations of the Mersey Railway." If the matter were merely a question as to the manner in which the work had been done, he was sure that there would be only room for the language of approval. No doubt the lifts in question would show as high a degree of merit and efficiency as lifts of that kind could possibly do. His main purpose, however, was to bring forward what he conceived to be a better practice, and one by which higher results could be secured at a less cost. For a few years past the tendency had been to avoid the use of ram lifts, in which the weight of the ram and cage was counterbalanced by means of weights and chain, and to employ what was thought to be a safer method, viz., the hydraulic balance. The firm whose work was under consideration had adhered, however, to the type now under discussion, and sought to avoid any dangers attaching to that method by excellence in workmanship. No doubt the result had been successful, so far as excellence of workmanship could ensure success; and he did not mean to say that the lifts under consideration were not Mr. Gibson.

Mr. Gibson. safe. The chains which attached the counterbalance weights to the lift were as strong as their weakest link. It did not appear from anything in the Paper what would be the effect of the breaking of the hand-rope; nor that there was any arrangement in such a case to cut off the pressure or close the valve at the end of the stroke. He confined his attention for the present purpose to the three lifts at the James Street Station. It was stated that these lifts had a stroke of 76·6 feet, and that each one was designed to lift one hundred passengers. The rate of motion was given as being 2 feet per second, corresponding to thirty-eight seconds for the rise. Making a proper allowance for the time consumed in receiving one hundred passengers into the cage, discharging them at the top, receiving other passengers wishing to descend, and discharging them at the bottom, it would appear that about twenty-five journeys per hour could be accomplished each way; and that seven thousand five hundred passengers could in that time be lifted in the three lifts to the upper level. He did not go into the question of the cost of doing this, preferring to assume that the highest possible efficiency and economy had been secured of which this type of lift was capable. He should have preferred to fix in the space occupied by these three lifts, either three lifts of much less area, or, if the same area were required, not less than six lifts. The lifts now there were moving at the rate of 2 feet per second, or 120 feet per minute; which rate of speed Mr. Rich conceived to be fast enough, "considering the great inertia of the moving loads, and the responsibilities involved. The total moving mass when a lift is fully loaded is nearly 30 tons." He was not in possession of any information as to the amount of traffic actually accomplished or expected. It was safe to assume that the traffic was great at certain hours of the day, and considerably less at certain other hours. Using six lifts, having a combined area the same as that of the three now employed, he would move them at a speed of say 350 feet per minute, and each of them should carry fifty passengers, assigning to each passenger the same space as that now provided. If it was thought that a speed of 350 feet per minute was too great, he had only to say that with an experience, extending over many years, he had invariably found that with men of business the highest attainable speed was demanded. It was fair to assume that nearly all those who would use these lifts at the Mersey tunnel would use them habitually, and while it might be true that those using the lift for the first time did not desire high speed, it was quite true—even in the case of ladies—that as soon as they became a little accustomed to it

they preferred it. In the important business office-buildings of New York, the speed was from 300 to 400 feet per minute, in some cases even greater than 400 feet. In these instances it was required to stop at the different floors. In the tunnel lifts there was this additional reason in favour of high speed, that there were no intermediate stops. With six lifts, in place of three, moving at that high speed, and each able to carry fifty passengers, the duty which could be accomplished, making the same proportional allowances for time consumed in receiving and discharging passengers at the end of the stroke, would be sixty journeys per hour each way. Each one of the lifts could raise three thousand passengers per hour; three of them could raise nine thousand per hour—fifteen hundred more than the three now used; and the six could raise eighteen thousand passengers per hour. The machinery made to do this would show the same efficiency as that which had been constructed. It had been stated in the Paper that "the total cost of the six lifts, with all their attendant machinery, was about £20,000." He had not, of course, gone into any careful computation of the cost of doing the work, but he had no hesitation in saying that the American Elevator Company would be very happy to take a contract at that price; to furnish six lifts, having the power just described; and the result would be eminently satisfactory as to profit. The expense of boring would be avoided. There would be no troubles as to the obtaining, or the possible disturbance of, verticality of cylinders; and, in the opinion of many eminent engineers, this might be done with at least as low a cost for power as had been reached, and with a degree of safety unsurpassed. If the three existing lifts could perform all the service required, then three of the rapid lifts to which he was referring would perform an even greater service, and the expense of the plant would be proportionally diminished. The total moving mass of one of these cages, if made for fifty passengers, would be about 8·5 tons, as against the nearly 30 tons involved in each of the present lifts; or if there were three cages, each cage designed to lift one hundred passengers, the total moving mass would be 16·95 tons; and these figures had their proper bearing upon the question of speed. He hoped to be able to enlist serious attention to this matter of rapid lifts, of the type called the Standard Hydraulic Elevator. It might be known to few of the members that his company was connected with the largest makers of lifts in the United States. There were now about four thousand of these hydraulic lifts in working. At the end of the first half of the year 1884 there were in the city of New York Mr. Gibson.

Mr. Gibson. alone five hundred and twenty-one of these lifts for passengers, and nine hundred and seventy-six exclusively for goods. A careful estimate had been made of the amount of duty done by these lifts in New York alone, and it had been estimated that the goods lifts were carrying daily more than 10,000 tons of merchandise; and that the passenger lifts were carrying daily more than four hundred thousand passengers. It might give a better idea of the amount of this service if he remarked that at the completion of the Inner Circle Railway, in September 1884, Sir Edward Watkin said that in the preceding year the Metropolitan Railway had carried eighty-five millions, and the Metropolitan District Railway forty millions, making one hundred and twenty-five millions per annum; or, three hundred and forty-two thousand four hundred and sixty-six per day; so that therefore these lifts were carrying in New York more people per day than the Underground Railways of London. This was, as he said before, estimated, but the estimate had been carefully made, and he had no doubt as to its accuracy.

Sir D. Fox. Sir DOUGLAS FOX said that Sir James Brunlees and he felt that it was appropriate that his brother Mr. Francis Fox should be the Author of that Paper, because they were both much indebted to him for his watchful care over the details of the work. Mr. Baker touched the key-note with reference to this enterprise when he said, while speaking about the way in which physical difficulties had been met, that there were no doubt other and greater difficulties to be faced, before the work was carried to completion. He thought it was his duty therefore to emphasize very distinctly the words which were found on the first page of the Paper, where the financial difficulties were spoken of. All who were in any way connected with the Mersey Railway realized that it would never have come into being, at any rate at that time, if it had not been for the enterprise of Major Isaac, who came forward when not only, he was sorry to say, a great many engineers, but the majority of the inhabitants of Liverpool and Birkenhead were opposed to the project, not as a question of traffic—they all believed in that—but from the notion that the river was impassable. This gentleman, with his friends, risked over £100,000 in order to prove distinctly, that it was possible to put this tunnel under the river. He should also like to say that the Engineers of the Company were most fortunate in the fact, that the work which they had to surpervise was entrusted to such eminently practical men as Messrs. Waddell and Sons of Edinburgh. They imported into the work a great experience in tunnel construction, together

with that energy which was found so often on the other side of the Tweed; and they also brought with it a very important characteristic, namely, extreme caution; the consequence was that, with their assistance, the engineers were able satisfactorily to compass the difficulties which arose during the progress of the tunnel. The quantity of water met with was given in the Paper as between 7,000 and 8,000 gallons per minute, and no doubt the water from the first was brackish, or slightly brackish. It was quite true, as Mr. Shoolbred had pointed out, that the volume of water was affected by the rise and fall of the tide. The company had been rather unfortunate with reference to water, for the largest feeders that were met with had been tapped directly the first shaft had been sunk at Liverpool. A great deal of the success with which the work had been carried out had been due to the resolution that was come to at first to drive a drainage-heading, and not to attempt to deal with the water in the face of the working. This heading was driven from shaft to shaft, with gradients falling towards the shafts, and the water was thus carried away from the men as they worked. The heading at that time was a very interesting sight, as showing the energy with which contractors could deal with work of that class. The sight was also very interesting when the tunnel was in full work, after the drainage-heading had been driven, and the top-heading in the tunnel was proceeding with no less than twenty-four faces opened at the same time. It was by that means that the completion of the main tunnel followed so rapidly upon the drainage-heading. When the work was first proposed, all sorts of difficulties were suggested, the chief one being that everybody was quite certain that the sandstone was full of fissures, and that, through those fissures, the river Mersey would immediately come in upon the tunnel. It was only fair to point to the evidence of Sir John Fowler, Past-President Inst. C.E., who, in connection with a similar Bill for crossing the river a little higher up, at the same time when the Mersey Railway first came into existence as an authorized work, stated that, in his opinion, there might be fissures, but if there were, they would be the driest part of the work. That had always been also his opinion. Only one fissure had been encountered, and that certainly was drier than most other parts of the work; therefore the prophecy, as far as that was concerned, came true. With reference to the steep gradients, it was absolutely necessary to have gradients which would bring the line, at any rate, at the further end of Liverpool and Birkenhead, somewhere near the surface. Even the gradients that had Sir D. Fox.

Sir D. Fox. been adopted led to considerable difficulties at two of the stations, and to what certainly never had been done before, namely, the construction of passenger stations for a very large traffic, at a depth of about 80 feet below the surface of the ground. But those gradients were not so exceptionally difficult, because, as Mr. Baker had pointed out, they fell in one direction and rose in the other, and there was no intermediate station. The locomotives ran down the bank with just the least touch of the automatic brake upon the train, the consequence being that the other gradient was half conquered before the engine felt it. As a matter of experience, he wished to emphasize what was said in the Paper with reference to the use of blue and of brindle bricks. Where the pressure was great, and cement used for the brickwork, the rough brindle brick, a cheaper brick than the best blue Staffordshire, was much more efficient in holding the cement. With reference to the point raised by Captain Galton, the adoption of two single tunnels instead of a double tunnel, he need hardly point out to practical engineers that two single tunnels would be more costly than one double one. The matter had been carefully considered by Sir James Brunlees and himself before recommending the precise form of tunnel that was adopted. Another point was this. It was a fallacy to imagine that a single tunnel would be ventilated by the action of the train; his experience went to the contrary. Those who had occasion to travel over the temporary railway on Mont Cenis, would remember their experience in that respect. They had to pass through single avalanche galleries, and the effect was most oppressive. A short time since evidence was given with respect to the Ledbury tunnel, a single line, that the men were often found lying on the foot-plate of the locomotive when they arrived at the end, in order to avoid the noxious fumes. The fact was that a single tunnel would not be ventilated with only the passage of the trains, and mechanical ventilation must be applied, as in the case of a double tunnel, to obtain efficient ventilation. He had listened with great interest to what Mr. Barry said with reference to the Metropolitan District Railway. There was nothing further from his wish than to make any comparison between the two systems of ventilation as carried out in London and in Liverpool. He might, however, point out that in the case of the Mersey Railway, for a considerable length blow-holes were impossible, and in reference to the other part of the railway, whether it was prejudice on their part, or not, the Corporations of Liverpool and Birkenhead declined to allow them

Sir D. Fox. to be opened, on any terms, into the streets, and therefore the noxious gases had to be dealt with in some other way. Not only so, but the company had to compete with a most efficient ferry crossing the river, and, if it had been attempted to make the public put up with what perhaps might have been satisfactory in comparison with the fogs in London, he was quite sure the passengers would not have been satisfied. With reference to the lifts he would not go into detail, but would only say that Sir James Brunlees and he had very carefully considered several proposals from the leading English manufacturers of hydraulic machinery, before adopting the one now at work, and which was giving great satisfaction. He was sorry that they did not receive an offer from the American Elevator Company. He had the greatest respect for everything done in America, and he felt it a great honour to be a member of the American Society of Civil Engineers. They came to the conclusion that the system adopted was, on the whole, the safest, which was the chief thing to be considered. They felt that they were trying to some extent an experiment. Each lift carried one hundred passengers, and in fact three hundred could be carried at a time, because there were three lifts at each station, and they could all be worked together. The consequence was that, if a train came in with three hundred passengers, they could be taken to the top without delay. To do that, the direct-acting lift with its large ram, with a safety-bolt which had been rather lost sight of in the discussion, an iron bolt running up the middle of the ram, was considered to be, on the whole, the safest thing that could be selected. Great credit was due to Messrs. Beyer, Peacock and Co. for the way in which they had carried out the design of the locomotives. They were by far the largest, or at any rate the heaviest, engines that had been made. He did not say that was an advantage, but it was necessary in this case, and they had done their work admirably. They not only condensed well, but they gave just the tractive force that was required. They could stop or start with their train on a gradient of 1 in 27. They surmounted the inclines and took the curves with the greatest ease, and though they were so heavy and seemingly so cumbersome, yet when in actual work they were completely under control. There was not anything very new about the section of the tunnel; for it was much the same as Mr. Barlow's tunnel at Haverstock Hill. It turned out very satisfactory; it gave all the strength needed, and all the space for fresh air that was required. He felt sure that, if any of the Members would go down to Liverpool, and look over the Mersey

Sir D. Fox. Railway, they would agree that the work that had been executed by the Contractors was as good as even England had ever seen.

Mr. F. Fox. Mr. FRANCIS FOX, in reply upon the discussion, said that the cross-section of the River Tunnel was the same throughout, except for a short distance where the tunnel had to be lowered, in which case one section was coned into the other. With reference to the suggestion that the tunnel should be divided longitudinally by a vertical diaphragm, the experiment was, he understood, tried on the Metropolitan Railway, where, owing to the tunnel having been originally made for the broad gauge of the Great Western Railway, sufficient width existed to enable it to be tested. It proved, however, to be worse than useless. The train acted to some extent as a piston, and forced the smoky contents of the tunnel into the station beyond; but it also left sufficient smoke behind in its trail to cause inconvenience to the train following.

The other objections to this suggestion were that the tunnel required to be constructed of an additional width of 5 to 6 feet; and it must be borne in mind that if the train had to act as a piston additional power would have to be provided. It was, therefore, best to apply this power in the form of a fan engine, and to take away the smoke by a special ventilating air-way. Mr. Barry had referred in such a kindly manner to the subject of ventilation, that he preferred not to draw any comparison between the Mersey Railway and the Metropolitan Railways of London. There was a more delicate means of indicating the presence of bad air than any chemical test, which was readily applicable and in the possession of every one; the lungs and throat would discern the presence of sulphur when the most delicate chemical test failed to do so.

In addition to the passenger lifts there were at each station a staircase and an inclined subway, both of which were largely used. Undoubtedly the cost of pumping and ventilating were additional charges upon the cost of working the railway as compared with ordinary railways, and it was to meet these and other expenses that Parliament authorized the Company to charge a 5-mile toll over the 1 mile of railway beneath the Mersey. At present the traffic was purely local, but so soon as the contemplated junctions were effected, enabling through-passenger and goods traffic to be conveyed at through rates, the additional charges would not, it was anticipated, bring up the percentage of working expenses to the average of other railways. In reply to Mr. Baker's remarks as to the quantity of water to be pumped, the "feeder," as given in the Paper, was between 7,000 and 8,000 gallons per minute.

He was strongly of opinion that an ample margin of power should always be provided in such cases, so as to allow for accidents and for repairs. For each 1,000 gallons that had to be pumped, provision should be made for 2,000 or 2,500 gallons, and hence the figure of 18,800 gallons was given, not as the probable extent of the feeders, but as the margin of power provided. In reply to a suggestion that it would be better to fix an iron tube along the soffit of the tunnel, over the engine funnel, into which the products of combustion would be thrown, and drawn out by the fans before mixing with the air of the tunnel, this was carefully considered; and the conclusion was that, although at some future time, when the traffic became very heavy, it might be desirable, at the present time it was unnecessary. The corrosion of long iron tubes over the trains would be rapid, and the effect on the ventilation was open to some doubt. Mr. F. Fox.

The Author considered it due to Mr. Shoolbred to admit frankly that, had the cost of gasworks been included in the comparative costs between gas and electric lighting, the difference would have been very much less. But what the Company had to consider was what the comparative cost would be of gas or of electric lighting. In the former case gas was available on the spot, whereas, had electricity been adopted, complete generating plant would have been necessary. It must not, however, be forgotten that the price charged for 1,000 cubic feet of gas included interest on the capital expended by the Gas Company. Much credit was due to Mr. Mellard Reade for his scientific foresight in predicting the existence of the old river-bed, which was encountered in the construction of the tunnel.

It might be interesting to mention that, on the recent occasion of the visit of Her Majesty the Queen to Liverpool, the number of passengers who passed through the tunnel on one day was between 49,000 and 50,000, the greater number of whom travelled between five P.M. and midnight, thus proving that with a more distributed traffic the capacity of the tunnel would be very large.

Mr. Rich, in reply upon the discussion, said it was a matter of no small satisfaction to him that all those who had commented upon the lifts had practically admitted that they had been carefully designed, and were safe for passengers' use. Mr. Ward had expressed surprise that duplex-pumping engines, working without expansion, had been adopted; and he commented on the variation in length of stroke in all engines of this type. Mr. Rich admitted that, for steady pumping-duties, engines more economical than these in their steam consumption might have been adopted; but Mr. Rich.

Mr. Rich. the engines in question were called upon to stop and to start in a fraction of a second, and during five months they had worked the lifts direct, without the assistance of any top tank or accumulator. He thought it would be very inconvenient to apply rotative-pumping engines to work the lifts in so direct a manner. Moreover, the great simplicity of the engines gave advantages more than equivalent to the value of a little extra coal. In duplex-engines with long strokes of pistons and valve-rods, and steam-jacketed cylinders, such as those described in his Paper, the variation in length of stroke was very slight. It was thought by Mr. Ellington that a considerably higher hydraulic pressure from an accumulator, and greater speed, should have been adopted, and also that the lift-rams should under no possibility be subject to transverse strains, that they should never be in tension, and that 9-inch solid rams would have been preferable to the 18-inch hollow rams adopted. It was easy to prescribe such modifications, but what would be the effect of adopting a 9-inch solid ram in one of the James Street lifts? Let it be nearing the top of its stroke, with the cage empty, and still some thrust upwards upon the cage bottom. Then the weight of the counterweights and chains or ropes must be very much reduced, and the solid ram, which would weigh about 17,600 lbs., or 86 per cent. more than the hollow ram, must either be unbalanced altogether, or some complicated hydraulic apparatus must be introduced to balance it. If hydraulic balancing were adopted with a 9-inch solid ram, the thrust at the top end of the ram, with the lift fully loaded, and rising, would be increased from 11,900 lbs., as in the present lifts, to 34,700 lbs., and the margin of safety in the ram as a column would be reduced from 31, its present amount, to 4·1, which he would consider inadmissible. At the same time the margin of safety to resist unequal loading, as shown in the Appendix, would be reduced from 6·6 to 3·1. If a 9-inch ram, balanced with chains and counterweights, as in the present lifts, were adopted, the counterweights would have to be increased 60 per cent., and the chains, of suitable size to balance the displacement, would be loaded to more than "proof" load. Mr. Ellington considered that transverse loading on the ram should be impossible. The Author was fully aware that with a high and very stiff cage, and with guides, top and bottom, it would be possible to eliminate transverse strains; but in view of wear of guides and other contingencies, he would consider it imprudent even then to provide for no transverse strains being brought upon the ram; and in view of the large area of the cage in this case, he believed the system of four guides

acting in one plane, at the cage-frame level, was by far the best and safest to adopt. The chains were passed through hot oil before they were erected, and they worked over large pulleys with moderate loads on them, and in practice they caused no noise nor vibration. With regard to the speeds, numerous records had been taken, showing that in practice the attendants regulated the lifts to work at an average of rather over 2 feet per second. When last at Liverpool he entered B lift on an ordinary journey with forty-two passengers, and noted that it went from bottom to top in thirty-three seconds, and he thought that no advantage would be gained from working faster. Considerably more time was occupied by passengers in entering and leaving the lifts than was required for the actual journeys up and down. Referring again to the question of hydraulic pressure, he saw no advantage in adopting 700-lbs. pressure when lifts only were to be worked. The packings and wearing-surfaces certainly required very much more attention with high pressure, and such pressure could not be applied to work a long-stroke ram direct. For such large demands as those under consideration, the Mersey Railway Company could certainly do the pumping at considerably less cost than it could buy high-pressure water-power from any independent company, and consequently there was no object in using an inconvenient pressure in this case. Besides, he understood that the quotations submitted for high-pressure lifts, with all their attendant apparatus, were much greater than for the low-pressure system adopted. As regarded the mechanical efficiency of the lifts, he had found, by careful experiments on F lift, that the ultimate efficiency at low speeds was 86 per cent.; in other words, the foot-lbs. of useful work done in raising the maximum load which could be raised with the tank full of water, and the pumps shut off, was 86 per cent. of the foot-lbs. expended in allowing the water used to pass from high-water level in the top tank to the discharge-pipe orifice in the bottom tank, the lift at the same time being so counterweighted that it would descend freely when empty. Mr. Ellington had elsewhere shown that he would consider this 93 per cent. efficiency[1]; but certainly one complete cycle of operations must always be taken to determine such mechanical efficiencies, which must be the ratio of the useful work done to the potential energy expended. In practice, the lifts always readily raised the maximum loads. At a speed of 1·2 foot per second, working from the tank only, with the engines shut Mr. Rich.

[1] Institution of Mechanical Engineers. Proceedings. 1882. p. 119.

Mr. Rich. off, the efficiency was 78 per cent. With loads of 11,486 lbs. in F lift, and of 450 lbs. in E lift, at Birkenhead, rising simultaneously, with one engine only at work, the journeys were accomplished in fifty-four and thirty-two seconds respectively. With a load of 19,283 lbs. in F lift, corresponding to one hundred and thirty-eight passengers, of 10 stones each, the tank-pressure became valueless, but the engines raised it readily. Mr. Ellington commented on the friction due to the passage of water down the annular space between the ram and the cylinders, but he would remind him that the cylinders were of 3 inches larger diameter than the rams. In all the above considerations it must be remembered that, in practice, the engines discharged their quota into the lift supply-mains at their bottom ends near the lifts, so that a great deal of the pipe friction was neutralized in that way. The cages were longest from back to front, and the chains and counterweights neutralized transverse strains on the ram from crowding towards the back or the front. Side crowding alone, which was less likely to occur, was resisted by the transverse strength of the rams.

The remarks of Mr. Gibson were mainly directed to advocating the superior qualities of his American elevators, which the Author understood to be suspended lifts, depending partly for their safety on automatic safety-gears for gripping the guides if the ropes broke or became detached. From an experience of over thirty years in the construction and working of various types of lifts, by Messrs. Easton and Anderson, he must certainly protest strongly against the use of suspended lifts of any kind for such works as those under consideration. They were necessarily much more complicated in details, and the safety-gears in practice could not be depended upon. They would most probably be effective if the ropes were cut suddenly immediately above the cage; but there was considerable chance of their failing to come into action quickly enough if a detail of the apparatus at a distance gave way, leaving some residual strain on the suspending ropes at the cage top. Sluggishness in coming into action allowed the cage to gain in velocity, and if stopped abruptly after that, its inertia would probably carry away guides and safety apparatus together. Mr. Gibson talked of a regular speed of 350 feet per minute; but he evidently had adopted much lower speeds in such lifts of his construction as the Author had seen in this country. In his ideal lift, Mr. Gibson proposed to receive fifty passengers, to raise them 77 to 88 feet, to discharge them, to take in another load for the down journey, to descend with them, to discharge them into the lower hall, and be ready to take in another up-going load, in one minute for the whole cycle of

Mr. Rich. operations, and to continue such rate of service for hours. The proposition was simply impracticable. Mr. Gibson had asked what would happen in the Mersey lifts if the hand-rope broke? In such a contingency the lift would simply rise till the cage was a few inches above the top floor, when either the counterweights would ground, or water would be blown harmlessly out of the gland surrounding the lift-ram.

Correspondence.

Mr. Colyer. Mr. F. Colyer remarked that in his practice he had fixed the maximum speed of passenger-lifts at 120 feet per minute, as beyond this rate the motion was disagreeable to most people. Taking the average stroke of the lifts under discussion at 82 feet, the speed was 140 feet per minute, which, for ordinary working, he considered too high. The average speed which he had adopted for ordinary passenger-lifts was about 90 to 100 feet per minute. He thought all lifts should be periodically inspected by a Government official, and the speed regulated. With regard to the position of the counterbalances at the side of the lift, he believed he first used this plan now about seventeen years ago, when he determined to do away with all overhead gear of any kind. As many engineers had since followed in the same line, he assumed the plan had met with approval. As a means of attaching the guide-bars to the side walls, he thought stone templates, with bolts let in and secured by lead, and the guide-bars fixed by nuts, would be in all cases preferable to wooden bricks, which were liable to shrinkage. In some half-dozen lifts designed by him seventeen or eighteen years ago, the guide-bars were fixed direct to stone, and they were as sound now as the day they were first fixed. The V guide-bar was undoubtedly the best form; he thought Messrs. Easton and Anderson had been the first to introduce it. In Mr. Colyer's practice the bars were planed at the back, where they rested on the stone, as well as at the front or V faces; they were also planed at the ends where they butted. The stones to which they were fixed were left $\frac{3}{4}$-inch clear of the wall, and were dressed off to a dead plumb-line, thus ensuring that the guides were absolutely vertical. About the same time he had adopted the 3-feet well, as he had the same objection as Mr. Rich to small "bore" holes, which were seldom plumb. This was a very important matter, as the cylinder of the lift should hang free of the well, and be absolutely plumb.

The "hat" shaped leather packing for the ram was superior to

Mr. Colyer. the U-shaped, as it caused rather less friction. Leathers of the latter shape had been worked continuously in rams 9 inches in diameter by 65 feet length of stroke, in passenger lifts of his design, for at least nine years without removal.

He did not like the construction of the cage, or ascending room, especially the cross-forging and girders at the bottom; the cross, made as described, seemed very risky. He should prefer a cast-steel boss clipped between two wrought-iron riveted girders, and all the rest of the cage framed in wrought-iron or steel, without any timber, except for the floor and the lining of the sides. He preferred to make the top of the cage of plate-iron, to prevent injury to persons inside the cage, should anything fall from the top of the well-hole.

The projecting parts, for attaching the counterbalance chain in Mr. Colyer's plan, worked in a groove in the brick-work. The counterbalanced weights also moved in a groove, and slid in angle-iron guides attached to the side of the recesses, in the same way as the main guide-bars before described: by this plan absolute security to passengers from injury was ensured, in the event of breakage of chains. He preferred keeping the sliding guides up to the faces of the guide-bars by spiral springs; it gave a little elasticity, and prevented any grinding, especially when the cage was unequally loaded. Some years ago he used disks of india-rubber and steel plates, but the oil destroyed the rubber. He understood that overhead girders were used in Mr. Rich's lifts, but he thought it would have been better to have fixed the chain-wheels on the side walls, and let the chains work in recesses, as he had before described. For further safety, he was in the habit of constructing a strong floor on a level with the bottom of the wheels, to prevent anything falling on to the top of the cage.

He did not consider the starting-valve mentioned to be so good a form of valve as the solid piston kind, made on much the same plan as that of Sir W. G. Armstrong and Co. In this case the valve-pistons were made of hard bell metal, and the valve-seats of the same kind of metal; very little surface was given at the seat. About nine years ago Mr. Colyer tried another plan, by facing the bottom of the piston with leather or india-rubber, $\frac{1}{2}$-inch to $\frac{5}{8}$-inch thick, and letting them seat upon flat bell-metal faces. In the case of water containing fine sand, these valves stood the longest without leakage. He considered the valve-gear to be the most important part of a lift; the man working it should have absolute control of the apparatus, but

the "cam" motion actuating the valves should be arranged to open and close them very gradually. An air-vessel placed between the valve-box and the ram-cylinder prevented any shock in the cage from the passage of the water being opened and closed, or turned to the waste-pipe. He thought that the gear-rod or rope should not have more than 3 to 4 feet range, so that the man working the lift might have proper control over it. Mr. Colyer.

The pumping machinery seemed most efficient, and the automatic arrangements for stopping and starting it were very good. Mr. Rich had said "a single direct-acting ram was from the first selected by the Author as the safest and best principle to adopt." He fully endorsed this: it was the plan he had advocated for many years. He also thought with Mr. Rich that a 6-inch solid steel ram would have been unsafe, especially on account of the weakness at the joints. Mr. Colyer always condemned the use of any kind of hemp or metallic packing. He had never used anything but leather; the common packing not only much increased the friction, but scored the ram in the way described in the Paper. While on the subject of friction, he might say that careful experiments made in some passenger-lifts of his design, with rams 9 inches in diameter and about 70 feet length of stroke, showed that it did not exceed 5 per cent. This included all friction in the lifts, which were almost new, and where the guide-bars and all rubbing parts were very closely fitted.

Sliding-guides were, without doubt, the best, and his experience coincided with the Author's as to the friction of wheels and rollers; these should at all times be avoided. The gun-metal linings of the sliding-guides should be slightly rounded at the top and the bottom, to prevent them ploughing on the side guide-bars.

He had seen the lift a few days after the accident at the Grand Hotel, Paris, and agreed that defective design and construction was the cause, and that with the leading makers of English lifts such a thing could not have occurred. He was sorry, however, that cheapness, and not efficient and good work, had been the chief aim of some people of late years. Where human life was at stake, false economy at the outset was much to be deprecated. After an experience of at least twenty years, he had never known of any failure or serious accident to any hydraulic ram-lift made by any of the leading first-class firms. In his opinion the most suitable form of lift for the purpose had been chosen. The care taken in the design was evident from the description given in the Paper. Considering the magnitude and the high class of the work, he

Mr. Colyer. considered the time occupied in the erection of the lifts to have been small, and their cost moderate.

Major English. Major T. English, R.E., stated that the tunnelling machine alluded to as the Beaumont was one patented by him, and was worked by Colonel Beaumont in the Mersey tunnel, under a license from him, which had since been withdrawn. The Tunnel-Driving Company, Limited, now held his sole license to use it.

Mr. Reade. Mr. T. Mellard Reade wished to make a few remarks as to the geological aspect of the Mersey tunnel. In 1872 he read a Paper before the Liverpool Geological Society on "The Buried Valley of the Mersey," in which he expressed his opinion that a buried rock-channel of the pre-glacial river existed between Liverpool and Birkenhead, which would very likely be intersected by the projected tunnel works. In a letter to the *Builder*, February 4th, 1882, while the tunnel works were in progress, this view was more strongly insisted upon, and it was also restated frequently at public lectures. The grounds upon which this view was based was the existence of a deep channel, filled with boulder clay, under the town of Widnes, proved by many well-sinkings. These borings showed no evidence of the existence of lacustrine deposits, and it was therefore concluded that it was a veritable river channel, and not a lake basin, and further considerations of a rather complex character led to the belief that this pre-glacial river had its outlet in the present estuary between Liverpool and Birkenhead. As showing the bearing of scientific geology upon engineering work, the verification of this prediction was interesting. Sir Douglas Fox indicated that the borings in the river were undertaken because of the prevalence of this belief, and that the tunnel works were lowered 10 feet. This was an important result, as the consequent difference in the extent and nature of the section of glacial drift through which the tunnel was carried might mean the difference between a great success or a failure.

Mr. Upward. Mr. A. Upward, in connection with the subject of the ventilation of tunnels in which locomotive engines were employed, or, in fact, in any confined spaces in which fuel was consumed, observed that the purer the fuel consumed in such spaces, the better it would be for all concerned, both as regarded passengers and those who were responsible for keeping such confined spaces clear of obnoxious gases. The fuel to which he desired to direct attention was that made many years ago at some coke works at Llanelly, in South Wales, and called "anthracite coke," which was reported to be entirely free from sulphur. If fuel of this description were used in such cases as in the Mersey tunnel, it would certainly render

easier the task of keeping it free from sulphurous acid gas, and consequently it could be better and more economically ventilated. This fuel was made of pitch, produced from gas-tar and pure anthracite culm, of which there were large deposits in South Wales of little commercial value. At the time he was speaking of, he obtained it at about *2s. 6d.* per ton, and he had no reason to believe that it had since risen in price, and as gas-tar pitch was also a cheap substance, this fuel was produced at a cost of from *7s.* to *8s.* per ton. He believed the specific gravity of the anthracite coke was from 1·200 to 1·500, while that of the best oven coke, produced in the district named, was about 0·980. **Mr. Upward.**

The Locomotive Superintendent of the Llanelly Railway and Dock Company reported on this coke in 1861, and stated that the coke in question was superior to any his company had used for locomotive-purposes. He might add that a Manager of iron-works at Aberdare had reported, on this coke, that he had obtained highly satisfactory results, both as regarded economy and the superior quality of iron produced by its use. Other persons in the iron trade in Wales had reported that this fuel was a desirable substance to be employed in producing and remelting iron, it being entirely free from sulphur. He would suggest that if such fuel could be now used in underground railways, both the passengers and the railway officials, who had to pass so much of their lives in these confined spaces, more or less charged with obnoxious gases, would be greatly benefited.

Mr. RICH, in reply to the correspondence, said he was glad to find that Mr. Colyer's experiences on many points agreed so nearly with his own. Many of Mr. Colyer's remarks were answered by his reply on the discussion. Leather packings for the main ram glands and side counterweights had been used by Messrs. Easton and Anderson at dates considerably earlier than those mentioned by Mr. Colyer, and they had adopted a steel-plate roof for the cage in nearly every case when the balance-chain was central over it. He preferred attaching lift-guides to wooden sleepers rather than to stone, as they formed a more elastic bed, and he had found little inconvenience from their shrinkage. He had used piston-starting valves, but they were difficult to keep water-tight, and were generally inferior to those adopted on the Mersey works. He considered spiral springs to the guide-brackets would be too lively in such large and heavy cages as these, though he ordinarily adopted them in small lifts. The guides, as arranged, worked admirably. **Mr. Rich.**

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11 May, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President,
in the Chair.

The discussion on the Papers, on "The Mersey Railway" by Mr. F. Fox, and on "The Mersey Railway Lifts" by Mr. W. E. Rich, occupied the whole evening.

18 May, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The following Associate Members have been transferred to the class of

Members.

Henry Taylor Bovey, M.A.
Henry Deane, M.A.
Andrew Johnston.
Joseph Lobley.
Togarmah Rees.
John James Webster.

The following Candidates have been admitted as

Students.

Arthur Joseph Edwin Arch.
Joseph Peter Brazil.
Clarence Gordon Broomfield.
Leslie Everitt Clift.
Frederick William Cowie.
Frank Whinfield Crawter.
James Hening Cuming.
George Herbert Dawson.
Arthur Lennox Drummond.
William Farrington.
Malcolm Cumbernauld Flemyng.
George Edwin Fletcher.
Hector William Baillie Henderson.
John Llewellyn Holmes.
Samuel Joyce, Jun.
John George Gale Kerry.
Edward Newdigate.
Francis Reilly.
Edward Richardson.
Frederic David Sharp.
William James Taylor.
Francis Herbert Tyacke.
Charles Stanley White.
John Woodside.

The following Candidates were balloted for and duly elected as

Members.

Rookes Evelyn Bell Crompton.
Stephen Holman.
Francis William Martin.
James William Restler.
Peter William Willans.

Associate Members.

Henry Crowquill Ayris, Stud. Inst. C.E.
John Charles Beahan.
John Stennitt Bean, Wh. Sc.
Orient Bell, Stud. Inst. C.E.
Harry Robertson Best, Stud. Inst. C.E.
Nasarvanji Dorabji Bhada, Ll.E.
Henry Richard Carleton, B.E.
Charles Harwood Clarke.

Associate Members—continued.

Vivian Bolton Douglas Cooper.
Ernest George Craven.
William Cross.
Henry Herbert Gahan.
William Hill.
Charles Herbert Hopkinson.
John George Howard.
Fernando Harry Whitehead Livesey, Stud. Inst. C.E.
Robert London.
William James Martin.
Robert Comins Puckering.
William John Patrickson Storey, Stud. Inst. C.E.
Edwin Arthur Slade Templeton, M.A., Stud. Inst. C.E.
Harry James Thompson, Stud. Inst. C.E.
John Wakeford.
John Duncan Watson.
Wilhem Willink.

(*Paper No. 2158.*)

"Modern Machine-Tools and Workshop-Appliances, for the Treatment of Heavy Forgings and Castings."

By William Wilson Hulse, M. Inst. C.E.

The greatly extended employment of steel, and the increase in the weight and magnitude of forgings and castings both of steel and of iron, characteristic of late years of various branches of engineering, have led to important changes in machine-tools, in order to prevent a decrease in the quantity of work turned out. For not only is steel specially obdurate to the action of cutting, but it is usual, in steel forgings, to leave an excessive thickness of metal to be cut away, for the sake of economy in the forging and of the enhanced value of coarse steel cuttings in re-melting, as compared with fine ones. The requirements in machine-tools therefore have comprised increased power, strength, and massiveness; greater firmness of grip upon the work and upon the cutting tools; and also important modifications in the mechanical arrangements, one aim kept in view being, as far as practicable, to machine heavy forgings or castings at a single setting, and thus to reduce the number of removals and re-settings to a minimum. Naturally the changes which have enabled machine-tools to turn out as much work in steel as they formerly did in iron have at the same time improved their productive power when dealing with iron and other materials less tenacious than steel. Workshop-appliances for the treatment of heavy work have likewise undergone important modifications, which will be referred to later on.

As examples of the machine-tools and workshop-appliances in

question, the Author has selected the following for illustration and description, viz.:—

A powerful 40-inch lathe, with four cutting-tools and fixed twin screws.

A 34-inch lathe of extra strength and power, with eight cutting tools and fixed twin guide-screws.

A large universal planing-machine, arranged for planing lengthwise, or crosswise, or vertically, as in slotting.

A combined horizontal boring-machine and lathe.

A combined vertical and horizontal planing-machine of great size and power.

A universal horizontal drilling- tapping- and boring-machine.

A combined vertical milling- and drilling-machine.

A ribbon-sawing machine for sawing off "deadheads," and sawing metal in general in the cold state.

A 30-ton power travelling-crane, specially adapted for an engineer's fitting- and erecting-shop, and for steel-houses and foundries.

Spirit-levels used in erecting and fitting shops.

Plate 6, Figs. 1, 2, 3, 4 show the 40-inch lathe, with four cutting tools for turning steel guns, propeller-shafts, ingot-blocks, &c. The lathe is 75 feet long, and weighs about 100 tons. It is adapted for screwing, sliding parallel or taper work, and surfacing. It will take in objects between the centres, and over its sliding carriages, up to 60 feet in length and 5 feet in diameter, and it has been used for turning pieces weighing more than 60 tons. In order to diminish the load upon the centres when such heavy objects are being operated on, an intermediate stay (Plate 6, Fig. 1) fitted with two rollers, adjustable towards or away from the axis of the lathe, is fixed on the bed, the adjustment of the rollers being effected by diagonal screws. The fast head-stock has distinct single, double, and treble gear wheel-powers, each having five different changes of strap-power in the cone pulley, and two in the top driving apparatus, making in all thirty various powers or speeds available to suit the resistances to be overcome, which of course will vary according to the size and nature of the work, and the amount of metal to be removed in a given time. For giving great strength to the bed, it is made with two deep longitudinal box-girders, united by numerous transverse box-girders of less depth. It is constructed in three lengths, secured together by numerous bolts, which act also as steady pins for preserving perfect alignment. The width of the bed is 5 feet 6 inches, and its depth 2 feet. The main spindle is of hammered crucible

steel, the principal journal being 13 inches in diameter by 21 inches long, and the outer journal is formed with grooves, like a propeller shaft, to take the end thrust. The face-plate is of cellular construction; it has both external and internal gearing, and is fitted with four steel jaws, operated by independent screws, for gripping the work. The treble gear has a wheel-power of 150 to 1, and the cone driving-pulley, whose largest diameter is 39 inches, carries a double belt 7 inches wide. The spindle of the movable head-stock is actuated by hand through a worm and worm-wheel, which give the power requisite for forcing the centre into the countersink of the work. Two sliding-carriages are provided, each carrying a pair of duplex compound slide-rests and two cutting-tools, or four in all. Each tool takes a "cut" 1½ inch deep and over ¼ inch thick at the rate of 6 to 7 lineal feet per minute. This size and rate of "cut," if maintained continuously, would yield about 5 cwt. of steel turnings per hour for each tool, or a total weight of 10 tons of steel removed by all the tools per day of ten hours continuous working. Deduction, however, must of course be made on account of stoppages for changing tools and for other contingencies. Besides the great weight, strength, and cutting-power of the lathe, there are several noticeable features in the mechanical arrangement. Thus the sliding-carriages are operated by twin fixed guide-screws, placed one at the back and the other at the front of the bed on the outside, and of rotating nuts, which work upon the screws. Each sliding-carriage has two such rotating nuts, and is thus acted upon at two points widely separated from each other. This arrangement prevents the sliding-carriage from horizontal cross-winding on the bed, and diminishes the frictional resistance which would result from the traversing of the carriage along the bed, if propelled by only a single guide-screw, acting at one side as is usual. The guide-screws are made in two lengths, secured in bearings cast to the bed at the ends, so as to prevent it from rotating, and to receive the end pressure. The two lengths are joined together to ensure their alignment one with the other; but, as each length is held fast at the outer end, the joint is not subjected to torsional stress. The two rotating nuts in each sliding-carriage are driven simultaneously through gearing and shafts (carried by the sliding-carriage), actuated from a longitudinal steel shaft situated inside the bed. This shaft is rotated through change-wheels driven by the main spindle of the fast head-stock. The direction in which the nuts rotate, and therefore that in which the sliding-carriages traverse along the bed, is regulated in each carriage independently, by means of a clutch,

operated by the workman at the front of the lathe. The complete independence with which each sliding-carriage can thus be traversed in either direction, or be kept stationary without regard to the other, is an important advantage resulting from the employment of stationary, instead of rotating, guide-screws. In order to meet the requirements of screw-cutting, each clutch is made so that its teeth will engage in one relative position only. For the purpose of contending more effectually with the great upward stress to which the slide-rests at the back of the lathe are sometimes subjected, the front dove-tail of each of the top slides is pointed downwards as shown in Fig. 3. For turning taper objects, the sliding-carriage is fitted with mechanism, comprising a swing-frame and change worm-wheels, by which the cutting tools can be simultaneously traversed transversely and longitudinally at different speeds, according to the degree of taper required. For cutting off "deadheads" or surplus lengths of objects, such as large guns, propeller shafts, &c., the duplex compound slide-rests of one of the sliding-carriages are temporarily removed, and two parting-tool rests are substituted. Each of these latter carries a parting-tool 6 or 7 inches deep by 1 inch thick, and may overhang the rest by as much as 15 inches, being supported by a steel bar of similar section fixed in the rest along with it, but with rather less overhang. The two tools are fed inwards simultaneously from opposite sides, the strains produced thus being balanced, and the cutting-off is effected smoothly and without vibration.

Plate 6, Figs. 5, 6 show the 34-inch lathe with eight cutting tools. In this case the fixed guide-screws are situated inside the bed between its two outer girders, and each sliding-carriage is connected with only one of them, there being two sliding-carriages at the front of the lathe connected with the front guide-screw, and two at the back connected with the back guide-screw. The spindle is of similar construction to that in the 40-inch lathe, but of greater strength, the main journal being 15 inches in diameter and 22 inches long. The bed is in two lengths bolted together, each length being formed of four longitudinal girders disposed in pairs, equidistant from, and parallel to, the centre line of lathe, and connected together by numerous cross-girders, all of box form. It is of enormous strength. The two front girders support and guide the front sliding-carriages and tools, and the two back girders those at the back of the lathe, the front and back carriages being free to pass by each other when traversing along the bed. Each sliding-carriage carries one compound slide-rest fitted with two top slides, holding one cutting tool each, thus

making eight cutting tools in all. The cutting-tools may be traversed either longitudinally or transversely, automatically or by hand, and in either direction, or the action of any one may be suspended independently of the others. For actuating the mechanism, in the front and back sliding-carriages, through which the nuts are rotated, two longitudinal shafts, driven by change-wheels, are employed, one shaft at the front of the bed, and the other at the back, on the outside. Twenty-four different changes can be made in the rate of rotation of the main spindle to suit different requirements, and varying the power from a maximum of 200 to 1 to a minimum of 14 to 1. Both the size and the rate of "cut" are the same as in the 40-inch lathe, but, as the number of tools is doubled, the weight of turnings which can be cut off in a given time, when all the tools are at work, is also doubled, and amounts in the course of ten hours' continuous working to a maximum of 20 tons of metal removed. The length of this lathe is 45 feet 6 inches, and the weight about 80 tons. The class of work for which it is specially designed is the turning steel ingots or heavy steel forgings in the rough. It represents also the type of lathe used for turning large crank-shafts, except as to the height of centres, which for such objects must be considerably greater than in this lathe.

Plate 7, Figs. 7, 8, 9 illustrate the large universal planing-machine, capable of planing 30 feet long, 11 feet wide, and 10 feet high. There are two tool-carriages on the cross-slide, each actuated by a separate screw. The bed (which is cast with two longitudinal and numerous transverse box-girders) is 40 feet long, made in two lengths. The table is 33 feet long, cast in one piece strongly ribbed underneath, and has tee-grooves on the top face, planed to gauge, and at uniform distances apart. The machine is partly supported by two transverse girders, situated under, and bolted to, both the bed and the uprights; these girders serve to strengthen the bed against the transverse bending-strains to which it is subjected, by the overhanging weight of the uprights and cross-slide. It is arranged for planing objects lengthwise, or crosswise, or vertically as in slotting. The possession of the two latter functions renders the machine capable of treating, at a single setting, heavy objects, which otherwise might require several removals to, and re-settings on, other machines. The separate lengths, which compose the beds of the lathes already described, and which require to be accurately planed or slotted at the ends forming the joints, are examples of such objects. The transverse-planing operations are performed by imparting reciprocating

motion to one or both of the tool-carriages along the cross-slide; and for planing vertically as in slotting, the vertical tool-holder slides are made of increased length, and are traversed up and down by their screws, driven by a shaft in the cross-slide. The mechanism for performing these transverse and vertical planing operations is, as shown in the Figs., actuated from a special driving apparatus, carried at the top of one of the uprights. The reversing of the reciprocating motions is produced by means of a spirally grooved barrel, rotated through a worm and worm-wheel, at a slow speed, from an overhead driving apparatus; two adjustable stops are secured in the spiral groove, and alternately come in contact with a block, which slides in the spiral groove, and is traversed thereby. Each time one of the stops comes in contact with the sliding-block (which is carried and guided by a square bar) the driving-belt is shifted from one fast pulley to the other, and the direction of motion of the driving mechanism and of the spirally grooved barrel is reversed. The spiral groove makes four turns round the barrel; this number being sufficient for producing the reversals of the longest strokes which can be taken, either crosswise or vertically. In planing a horizontal surface crosswise, the table is traversed intermittently along the bed, for producing the cutting feed, but if the surface is vertical, then the tool-holder slides are traversed vertically for this purpose. Again, in planing vertically as in slotting lengthwise, the intermittent cutting feed is obtained by traversing the table; and in similar planing crosswise, by traversing the tool-carriages along the cross-slide. In all these cases automatic mechanism is provided for producing the cutting-feed. For planing lengthwise, the table is reciprocated by means of a large steel screw and travelling nut (in wider machines two screws and nuts are employed), the screw being driven at one end of the machine, through two friction cone-pulleys, carried by the driving shaft; one of these cone-pulleys serves for the forward or cutting traverse of the table, and the other for its return traverse. The steps of the cone driving-pulleys enable the speeds of the forward and backward traversing to be varied independently of each other, so as to suit the material under operation, in the case of the forward or cutting traverse, and to suit the weight of the object in that of the return traverse. The end thrust of the table-screw in either direction is taken by adjustable tail pins, and the screw, being of great length and weight, is supported between the end bearings by adjustable cylindrical rollers, placed at each side, at intervals of about 10 feet apart. The rollers dip in oil, and, being rotated as the screw

rotates, carry up oil to the screw, to be distributed by the travelling nut as it passes along. The travelling nut is partly cut away (without destroying the continuity of the thread), so as to allow it to pass by the supporting rollers without colliding with them. The V slide-surfaces of the table and bed are inclined to the horizontal line at an angle of only 15°, and for lubricating them a series of other cylindrical rollers, dipping in oil, and mounted upon axles parallel with the inclined surfaces of the V slides, are introduced. These rollers are arranged in pairs, each roller being free to revolve on its own small axle, and, being pressed against the surfaces by springs, the oil is carried up and distributed by the table as it travels along and rotates the rollers. In this arrangement the rollers are in mere rolling contact with the table, and are an improvement upon the double conical rollers often employed, which have the drawback of being in sliding or frictional contact with the V slides. The mechanism for producing the cutting-feed, when the machine is planing longitudinally, is actuated by adjustable stops secured to the right-hand side of the table, which, as the table traverses to and fro, alternately propel a rack backwards and forwards through a greater or less distance, according to the positions in which they are secured to the table. The rack gears into, and drives first in one direction then in the other, a spur-wheel, and through it a ratchet action; the arrangement being such that the feed-screws in the cross-slide, or tool-holder slide, as the case may be, remain stationary during the cutting traverse, and are rotated only during the backward or non-cutting traverse. The extent of the feed is regulated by the distance the rack is traversed, and by the number of turns it causes the spur-wheel to make. During the backward traverse of the table the tools are lifted clear of the work. By this means, the "cut" may be varied by gradations of $\frac{1}{64}$ inch up to 2 inches broad. It is applied only during the backward traverse of the table; whereas, under the system which has hitherto been common, it is applied suddenly, during the short time the driving-belt is being shifted for reversing the backward traverse of the table, and the utmost range in the width of "cut" is so restricted, that for broad cutting it has to be supplemented by hand. The machine, while having its tool-holder slides made to swivel in the ordinary manner, is also fitted with mechanism for planing inclined surfaces by means of change-wheels, which transmit simultaneous feed-traverse at different relative rates to the screws of the tool-holder slides and of the cross-slide respectively, according to the inclination of the surface to be produced. With the aid of this

additional arrangement, surfaces of any inclination can be planed; whereas, with the swivelling tool-holders only, the range of angles which can be produced is limited. The machine under consideration is arranged to plane at from 10 to 16 lineal feet per minute, returning at from 30 to 40 feet per minute, according to the nature and weight of the object operated on. At the slower traverses, objects weighing 60 or 70 tons may be safely dealt with, and this weight is not likely to be exceeded in practice. The machine is designed for planing the heavy foundation beds and frames of marine and stationary engines, machine-tools, armour-plates, &c. The cutting-tools used in this planing machine and in the two lathes, already described, vary from 2½ to 4 inches square, and are very powerfully gripped to the clapper, or tool-slide, as the case may be. For such heavy cutting as is done by these machines, tool-holding bars with cutters fixed in them are inadequate.

Plate 7, Figs. 10, 11 represent the combined horizontal boring-machine and lathe, designed for boring and facing medium-sized engine cylinders, and for work in general. It is likewise adapted for use as a surfacing and sliding-lathe. Fast and movable head-stocks are provided as in a lathe, each mounted upon a standard secured permanently to the foundation-plate. The fast head-stock has single, double, and treble powers, and a great variety of speeds, so as to meet the different classes of boring and turning the machine may be required to do. The main spindle is of steel, with its outer bearing formed with grooves, as in a propeller shaft, to take the end thrust. Between the two standards, and bolted to them both, is a horizontal slide-bed, which carries the sliding-carriage. This latter is traversed longitudinally along the bed by hand or power, by means of the guide-screw, and is provided with a tee-grooved table on which the work to be bored is secured, and which has a cross-slide and screw for transverse movements. The two standards have vertical tee-grooves on their inner faces for receiving the bolts which secure the horizontal bed to them, and if these are loosened, the horizontal bed can be raised or lowered by means of two vertical screws, thus affording an adjustment to suit different heights and kinds of work. The vertical screws are actuated either by hand or by power through a long horizontal shaft, as shown, carrying two worms, which gear into worm-wheels on the two screws respectively. The transverse and vertical adjustments of the tee-grooved table enable the work to be readily brought into correct position for boring, and an automatic movement longitudinally produces the cutting

traverse for boring and sliding. The boring bars, with cutters, are held between the centres of the head-stocks, and rotated by the face-plate and a driver; the object to be bored being fixed to the tee-grooved table, and traversed automatically or by hand in either direction. The hand-traverse is effected through a handle or shaft situated on the sliding-carriage. The bars for boring engine-cylinders are provided with an arm and radial slide, carrying cutting-tools, for turning the faces and rims of cylinders, &c., the arm being movable along the bar to any position. When it is required to use the machine either as a surfacing- or as a sliding-lathe, a compound slide-rest is secured to the tee-grooved table, the cutting-tool being made to operate on the revolving work, whether fixed to the face-plate or between the centres. The longitudinal cutting-traverse employed for boring serves also for sliding, and that for surfacing is transmitted, through a crank and chain, from the fast head-stock to an ordinary ratchet action applied to the transverse screw of the sliding-carriage. The machine described is capable of boring engine-cylinders up to 30 inches in diameter, and of turning and surfacing work up to 48 inches in diameter; and the power and strength are unusually great for its capacity. This combination of a cylinder boring-machine and lathe is intended to meet cases where the number of cylinders, or other objects to be bored, is not sufficient to employ the machine solely on such work. When, however, there is sufficient of it, the slide-rest and other parts specially adapted for turning purposes are omitted, leaving then a machine specially adapted for boring and facing cylinders, plummer-blocks, and such like objects of moderate size.

Plate 6, Figs. 12, 13, represent the combined vertical and horizontal planing-machine. It weighs about 90 tons, and is capable of operating over a vertical plane 20 feet long, by 15 feet high, and over a horizontal one 20 feet long, by 3 feet wide; the "cut" in the former case being taken either in a horizontal or in a vertical direction. The cutting-tool is fixed to a compound slide, which is traversed vertically by a guide-screw working in a vertical slide-bed, and is balanced by a weight suspended inside this bed by a chain. The vertical slide-bed is secured to two carriages, which traverse upon two horizontal slide-beds. The traverse along these beds is produced by means of two guide-screws, rotated simultaneously by a vertical shaft and bevel-gearing, actuated from the driving apparatus, which, through a horizontal shaft and bevel-gearing, also operates, alternatively, the vertical guide-screw. The two horizontal slide-beds are made separately (for convenience

of transport), and are bolted together so as to form a complete frame, which is bolted to three strong uprights. These are of box-section, having at the bottom projecting spurs to which is bolted a tee-grooved bed, on which the work is secured. There are three distinct automatic cutting-feed actions, one for planing vertically lengthwise, another for planing horizontally lengthwise, and the third for planing vertically crosswise. The first two actions are effected by respective ratchet-wheels, actuated through shafts and adjustable stops, connected with the particular traverse motion which may be in operation. The third action is obtained by a star-wheel, which, at each stroke of the compound tool-slide, comes in contact with an adjustable stop, fixed in a groove formed in the vertical slide-bed. The tool-holder has a swivel-slide, as in an ordinary planing-machine, by which the tool can be set so as to plane angular work, the cutting-feed of this slide being non-automatic. The whole of the mechanism is operated from one driving apparatus, conveniently placed at one side of the machine, and provided with two fast pulleys and one loose one, the former transmitting motion to the mechanism, in either direction, through differential spur-gearing, which gives a slow cutting traverse, and a quick return movement to the cutting-tool. These differential motions are transmitted by means of bevel-gearing, either to the vertical or to the horizontal shaft, previously mentioned, according to the direction in which it is required to perform the planing operation. For some descriptions of work, it is useful to fix on the bed a tee-grooved table about 8 feet square, having compound rectilinear and circular slides, as in a slotting-machine table, to enable circular and curved, as well as flat work, to be planed. This addition likewise gives greater facility in "chucking" the smaller class of objects, and in adjusting them to the tool, and renders frequent resettings, when there are several surfaces to be planed on the same object, unnecessary. These combined vertical and horizontal planing-machines, are principally used for machining cylinders, standards, bed-plates and other large objects in marine-engine establishments.

Plate 6, Figs. 14, 15 represent the universal horizontal-drilling, tapping- and boring-machine. It will operate over an area 16 feet long by 10 feet high, and is designed for dealing with such objects as the main frames, bed-plate, cylinders, condensers, and other parts of engines. There are two standards which can be traversed horizontally to and fro along a slide-bed by means of a fixed screw, acted upon by rotatory nuts carried by the standards. The work is secured upon a tee-grooved foundation-bed bolted to

the slide-bed. Each of the standards is provided with a drilling, tapping and boring spindle, mounted on a carriage, movable up and down the standard automatically by a rotating vertical screw. For drilling and boring, the spindle is provided with variable automatic feed and quick-hand actions, and, when tapping work, the automatic mechanism is put out of gear, the spindle being left free to slide inwards and outwards under the influence of the tap, while the latter is cutting or returning. For rotating the spindles of the two carriages, two sets of driving apparatus, having both single and double gear, with four-speed cone-pulleys, are provided at opposite ends of the machine, the motion being transmitted to the spindles through shafts and gearing. For traversing the standards along the slide-beds, and the spindle-carriages up and down the standards, a horizontal shaft common to both standards is employed. Each standard is connected with this horizontal shaft through two sets of clutch bevel-wheels; one set traverses the standard along the slide-bed, through a pair of spur-wheels driven in either direction, and actuating the rotatory nuts; and the other traverses the spindle-carriage up and down the standard through a vertical shaft, driven in either direction, which actuates the vertical screw, through a pair of spur-wheels. The spindle-carriages are furnished with platforms, on which the attendants stand, and are carried about, having always within convenient reach the hand-wheels and levers for putting in action or suspending each and every function of the machine. In some of these machines one vertical standard only, with its traversing and drilling mechanism, is employed; but in such machines the range or capacity is less than in the one described.

Plate 7, Figs. 16, 17 represent the combined vertical milling- and drilling-machine. Its weight is 6 tons. The main frame is of strong box-form, the spindle projects 24 inches, and has a vertical movement of 18 inches. The means adopted to keep the lower end of the spindle rigidly supported against the lateral pressure of the "cut" at all points of the spindle's traverse, is a noticeable feature; the object being to give greater hold upon, and steadiness of action to, the milling-cutters, and thereby to ensure better work and more of it. The spindle, instead of running in bearings fixed to the body of the machine, works in two conical bearings within a hollow square slide, which is movable vertically through square guides formed in the body of the machine, and carries the spindle along with it. The lower conical bearing is close to the head of the spindle, and a locking-screw is provided for holding the square slide firmly in position at any desired point of the vertical adjust-

ment. The vertical slide, spindle, &c., are over-balanced by a weight suspended to a chain passing over a pulley, so as always to maintain a limited pressure upwards against a screw, provided for traversing the spindle, &c. The spindle is rotated by a long spur-pinion keyed to a vertical shaft, and gearing into a spur-wheel of ordinary width keyed upon the spindle. This latter wheel traverses along with the spindle, and the length of the pinion which drives it is such that both are constantly kept in gear. The vertical square slide and spindle are moved up or down automatically, or by hand, by means of the screw already mentioned, which is situated immediately above the slide, and is connected thereto. In most milling operations a continuous traverse of the spindle downwards is not required, and consequently, after adjustment, the vertical slide may in these cases be firmly locked in position, and released when an additional feed is required. A separate self-acting continuous-feeding mechanism is provided for drilling or boring, to be brought into play when required. The table on which the work is secured consists of a tee-grooved top (surmounted by a trough to receive the cutting lubricant), and two pairs of horizontal transverse-slides, with a worm-wheel between them. The worm-wheel works round in circular guides fixed to the top slide of the lower pair, and its upper face is formed as a slide, with bevelled edges, to serve as a guide for the bottom slide of the upper pair. The upper pair of slides and screws is provided for the purpose of readily adjusting the position of the work, in relation to the axis of the worm-wheel, with accuracy, and without removal after it has been secured upon the table. When the work has been adjusted, the two slides of the upper pair are made fast by means of locking-screws and pads, acting against the bevelled edges, which, in this pair of slides, are unusually acute. In straight line, or circular work, the lower slides and the worm-wheel, by means of their screws and worm respectively, traverse and guide the work against the cutting edge of the revolving cutter, and the profile of the work, in plan view, is determined thereby. For curvilineal, or irregular profiles in plan view, the bottom slide of the lower pair is disconnected from its screw, and is made free to traverse horizontally; and, by means of a balance-weight, a "model" of the outline is kept pressed against a circular "former," whilst at the same time the object is kept pressed against the revolving cutter. The "model" is usually fixed on the table, and the circular "former" to the spindle or the vertical slide. Profiling processes are extensively adopted in machining the sides and ends of cranks, levers, &c. The circumferential speed of the

cutters averages about 35 to 40 lineal feet per minute in cutting iron, and somewhat slower in cutting steel, and the gearing is arranged for the driving-strap to run between 250 and 400 feet per minute. In larger machines the power is increased. The working parts, viz., the cutter, spindle, &c., are also made larger and stronger, and the cutter is supported by a bearing underneath, where practicable, as well as by the two bearings in the square slide. In other respects the design and general arrangement of the machine are as in that represented in Plate 7, Figs. 16 and 17. Some machines, especially adapted for profiling work, are designed more after the style of a planing-machine. They are provided with a slide-bed, traversing grooved table, uprights, and cross-slide. The revolving cutter and spindle are carried by a vertical-slide, and traversed up and down by hand, or (when cutting profiles in elevational view) acted upon by a weight. This vertical-slide is in turn carried by a horizontal one, fitted to the cross-slide, and traversable across by hand or by balance-weight. The object to be profiled is fixed to the traversing table, with the "model" alongside (when one is employed); the "former" being fixed beside the cutter-spindle on the vertical-slide. The table is traversed automatically along the slide-bed, the extent of the traverse being controlled by stops, which arrest the action.

Plate 7, Figs. 18, 19 represent the ribbon sawing-machine for sawing off ingot heads, and for sawing metals in the cold state in general. The ribbon-saw overhangs the frame nearly 8 feet, is 2½ inches wide, and is carried by two pulleys, each 8 feet in diameter, with the centres about 9 feet apart, and making about 4 revolutions per minute. The upper pulley is secured upon a revolving spindle, carried by a sliding-block, which is free to move vertically, in guides formed in the standard of the machine. The block is raised or lowered by screw and nut, and is connected with a balance-weight and lever which pull at it in an upward direction, and hold the ribbon-saw in tension to the requisite degree. The lower, or driving-pulley has a large spur-wheel cast on one side of it, and is rotated by a cone pulley and double gearing, which impart the requisite power and speed to suit different depths and kinds of work. For carrying the work there are two sliding-tables, placed side by side parallel to each other, in the same horizontal plane, and mounted upon two slide-beds. They are arranged with a narrow space between them, forming a gateway for the saw, are both formed with tee-grooved tops, and are traversed simultaneously when the sawing operations are being performed. The traversing is effected by screws, driven by change-

wheels, through a worm and wheel. The worm can be put in or out of gear for starting or suspending the traverse of the sliding-tables, by a rod placed alongside one of the slide-beds. The engagement of the worm is effected by hand only, but the disengagement may be performed either by hand or automatically. In the latter case a stop on one of the sliding-tables comes in contact, at the right moment, with an adjustable stop on the sliding-rod, and pushes it along until the worm is disengaged. Two rollers, one above and the other below the plane of the sliding-tables, are provided, for supporting the saw when in operation; the upper roller being adjustable vertically, to suit different depths of work. The greatest depth of work through which the machine is adapted to saw is 15 inches, the speed of the saw is about 40 to 50 lineal feet per minute, and the pitch of its teeth varies from $\frac{1}{8}$ inch for shallow cutting, to $\frac{1}{4}$ inch for deep cutting. The machine is a large and powerful one of its class, and the framing is heavy and strong, so as to prevent vibration and save the saw. It is used for removing "deadheads" from heavy steel castings, and for work in general. In some cases the ribbon-saw is supplanted by a circular-cutting disk, or saw, 6 feet or upwards in diameter, revolving between the two sliding-tables, and carried upon a horizontal spindle (situated below the slide-beds), driven by a worm and worm-wheel. Ten to forty bar-cutters (according to the nature of the work), are fixed by screws in recesses formed in the two faces of the disk alternately. In this arrangement no part of the machine, except the disk, stands higher than the sliding-tables, so that any size or shape of work can be treated upon it. A lathe, where applicable, is preferable to any other machine for cutting off "deadheads" and the like; but with such forms as stern-posts, propeller-blades, &c., which cannot be readily chucked and rotated in the lathe, circular-cutting or ribbon sawing-machines are preferred for the cutting-off operations to either slotting or drilling.

Plate 7, Figs. 20, 21 represent the 30-ton traveller crane, having a span of 30 feet, and one of the distinguishing features of which is that the crab is a fixture upon the traveller, instead of being movable along it, and that a "bogie carriage" is employed for traversing the load transversely. This enables the crane to operate over a wider area of workshop floor than is possible with the movable crab usually employed, because of the greater length of the latter. In the Figs. the crab is shown fixed on the top of the traveller, at one end of it. In some cases, however, it is more convenient to have it fixed either in the middle of the traveller, on the top side,

or at one end of the traveller, on the under side, for the purpose of saving head-room. Another feature is the arrangement of the chain for lifting and lowering, which is all in one length, but led in two symmetrical lines, so that the load always hangs centrally between the two transverse girders and strains each line of chain, and each transverse girder, equally with the other. The two ends of the chain are connected to the barrel at points equidistant from the ends of the latter; and the two lines of chain, after leaving the barrel, extend across to the opposite side of the traveller, where they take a part turn round two vertical sheaves on the traveller-framing. Thence they extend first to vertical sheaves in the bogie carriage, and in the lifting-hook block suspended therefrom, and next, and last, to a horizontal sheave on the traveller-framing, under the crab. This horizontal sheave thus receives the chain at the middle of its length, and acts in a compensatory manner, so as always to keep each line of chain strained equally with the other. The barrel is grooved spirally to the right hand at one end, and to the left hand at the other, for directing the lapping around it of the two lines of chain. The bogie carriage is traversed by a chain carried over two sheaves, one on the traveller-framing and the other in the crab, the one in the crab being formed with teeth, for driving the chain in either direction. To enable the barrel to be kept low down, without interfering with the chain which actuates the bogie carriage, the barrel is formed with a deep groove in the middle, which allows the traversing-chain to pass. A quick-running rope is employed for driving the crane, and all the various movements are transmitted through a horizontal shaft in the crab. This shaft is provided with three sets of friction-clutch bevel-wheels, through one set the barrel is actuated for lifting and lowering; through another the bogie carriage is traversed transversely, and through the third the traveller is traversed longitudinally. In each case a worm and worm-wheel are employed for reducing the speed of rotation, and for retaining a hold of the load and of the traversing parts. In the case of the lifting and lowering mechanism, two changes of spur-wheels are also provided for varying the speed. The three clutches are operated through three hand-levers, situated close together, and having concentric axes. The attendant stands upon a platform, so arranged that he can readily observe what is going on below, and at the same time control and work the levers. As the crab is fixed to the traveller, the shaft which runs along the cross-girders, for traversing it longitudinally, does not require to have its intermediate bearings made movable,

as in previous practice. When the lifting-chain is required to be of such length that it cannot conveniently be lapped upon a barrel, two cable-holders (as in a ship's anchor-capstan) are employed instead of a barrel, and lockers are provided for the slack chain. These cranes are in some cases arranged to be driven by a long shaft, or else by a steam-engine carried upon the crab, either of these systems being preferable to the quick-running rope for steel- and iron-foundries. The working of the crane is remarkably smooth and noiseless, and its several actions can be started, reversed, or stopped instantly, and can be worked, in any order of combination, with perfect ease and precision, by an ordinary labourer. Added to this, the peculiar construction of the friction-clutches enables them to be worked steadily, with such amount of slip as may be desired, so that the loads can be adjusted, either vertically or horizontally, and gradually and with such nicety, as to render the crane of great value in erecting and fitting together work of the heaviest description. For steel-melting houses, foundries, &c., this type of crane is well adapted, because the attendant is not exposed to the fumes and heat rising direct from the molten metal as he stands at the side of the building opposite to the furnaces. The levers, moreover, may be actuated from the ground when preferred. In the Figs. the traveller and the bogie carriage are shown carried upon four travelling-wheels; but in cranes for lifting weights of 100 tons or upwards each would be carried on eight wheels, coupled in pairs by compensating beams, so as to ensure that every wheel shall have its due share of the load.

Plate 6, Figs. 22, 23, 24, 25 represent two kinds of spirit-levels as used in the Author's fitting- and erecting-shops. One is for testing horizontal lines and surfaces, and the other vertical ones. In both cases the tubes are graduated with divisions so proportioned that when the work tested is not truly horizontal or vertical, as the case may be, the extent of the deviations, measured in $\frac{1}{250}$ inch per foot of length, is shown by the number of divisions by which the bubble in the tube deviates from the central position. This method of testing lines and surfaces in constructional work is highly approved of in practice by the workmen. Since its introduction the use of squares in the Author's workshops has been greatly reduced, and that of parallel straight-edges (formerly used as winding strips) has almost died out.

Rectangular surface-plates, cylindrical gauges of size, table chucks, and other workshop-appliances remain unaltered in principle and design, but their size has of course been increased in harmony with that of the work to be treated.

In concluding this Paper, the Author would explain that his object has been, not to give an exhaustive account of the subject treated, but rather to make prominent such portions of it as appeared of chief importance, and therefore most likely to interest the members of the Institution.

The Paper is accompanied by numerous tracings, from which Plates 6 and 7 have been prepared.

[DISCUSSION.

Discussion.

Mr. W. HULSE wished to explain that of the two levels, one was the ordinary long spirit-level, and the other with a leg at right-angles to it. The latter was for levelling vertical surfaces, and the former for the ordinary horizontal surfaces. Both were acting very well. Mr. Hulse.

Mr. ALFRED MUIR considered some of the diagrams very imperfect in the details. The large lathe showed a bearing for the pinion which drove the face-plate with no cap to it; this was wrong in construction, as in case of a gall the bearing would have to be cut away to get the shaft out, and in case of the shaft wearing it would need renewal, whereas with a cap it could be closed. As to the boring-machine and lathe combined, there was a long bed supported at each end by two screws; this was a very faulty construction, and he would defy any one to make two screws in the ordinary way perfectly true. The gearing also to work these two screws was an element of inaccuracy; the result would be that in lowering or in raising the table, it would not be parallel with the spindle of the lathe. In the vertical and horizontal planing-machine, he thought the table was extremely weak; if a bridge were made on the same system he should expect a disaster like the one at the Tay Bridge. He considered the vertical milling- and drilling-machine an abortion; with the very unequal wear there would be on the long pinion it would in time be like a crooked stick. He regarded the crane as neither bad nor yet good. Mr. Muir.

Mr. R. H. TWEDDELL thought that a Paper like the present one should be treated in a broad and general spirit, not so much with reference to the many minute details, which the Author had so generously supplied, as to the general advancement of knowledge in that branch of engineering. He would therefore confine his remarks to the subject of the necessity of labour-saving machinery. He had had the honour, three years ago, of submitting a Paper on that subject, in which he had remarked: "At present a large amount of lifting is done by manual labour, especially in putting on, adjusting, and taking the article off the machine; in this there is great room for improvement."[1] The Author had not been long in responding to that challenge, one of his objects being "to machine heavy forgings and castings at a single setting, and thus reduce the number of removals and re-settings to a minimum." That was only another way of doing what Mr. Mr. Tweddell.

[1] Minutes of Proceedings Inst. C.E. vol. lxxiii. p. 71.

Mr. Tweddell. Tweddell had spoken of in his Paper. The Author, by diminishing the number of settings and re-settings, naturally reduced the number of liftings and takings-off. Where he had advocated putting down an increased number of small cranes and lifting appliances, the Author had brought out a class of machinery calculated to deal with objects which, when once placed in the lathe, required as little shifting as possible. He should have been glad if the Author, with his great experience, had said something as to how far it was wise to go on increasing the size of castings and objects now requiring to be manipulated. Castings were now made of enormous dimensions, involving considerable risk and great expense for railway-carriage, which was a serious matter in meeting foreign competition. It was time that this and other questions should be taken seriously into consideration. If an accident, for example, occurred to one of the enormous propeller shafts now made, the cost of replacing it was so great that it was worth considering whether it would not be better to have more couplings and connections, and a greater number of parts, thus reducing the size of the pieces affected. As another example of the ever-increasing dimensions of machine tools, engineers were now putting 150 tons on a rivet-head at each operation, while twenty years ago 20 tons was thought enormous. This Paper was of great value as indicating an epoch in machine-tool manufacture. The last Paper of the kind which he remembered was one read by Mr. James Fletcher before a kindred Institution in Glasgow in 1864,[1] and it was as interesting at that time as the Author's was to-day. Mr. Fletcher's Paper treated of the change from wood to iron in ship construction; the Author's on the change from iron to steel, and the increased power of machine-tools required to deal with the new material. Additional interest would be given to the Paper if some data were afforded as to the power required to work steel as compared with iron—the increased resistance offered by the new material, especially the softer kind, in comparison with the best iron. He very much questioned whether the resistance in the softer kinds of steel was as much greater as was generally supposed. The 30-ton travelling crane was certainly a good example of that kind of crane, but he thought there was not much novelty in keeping the driving-gear apart from the travelling monkey, at all events not to hydraulic

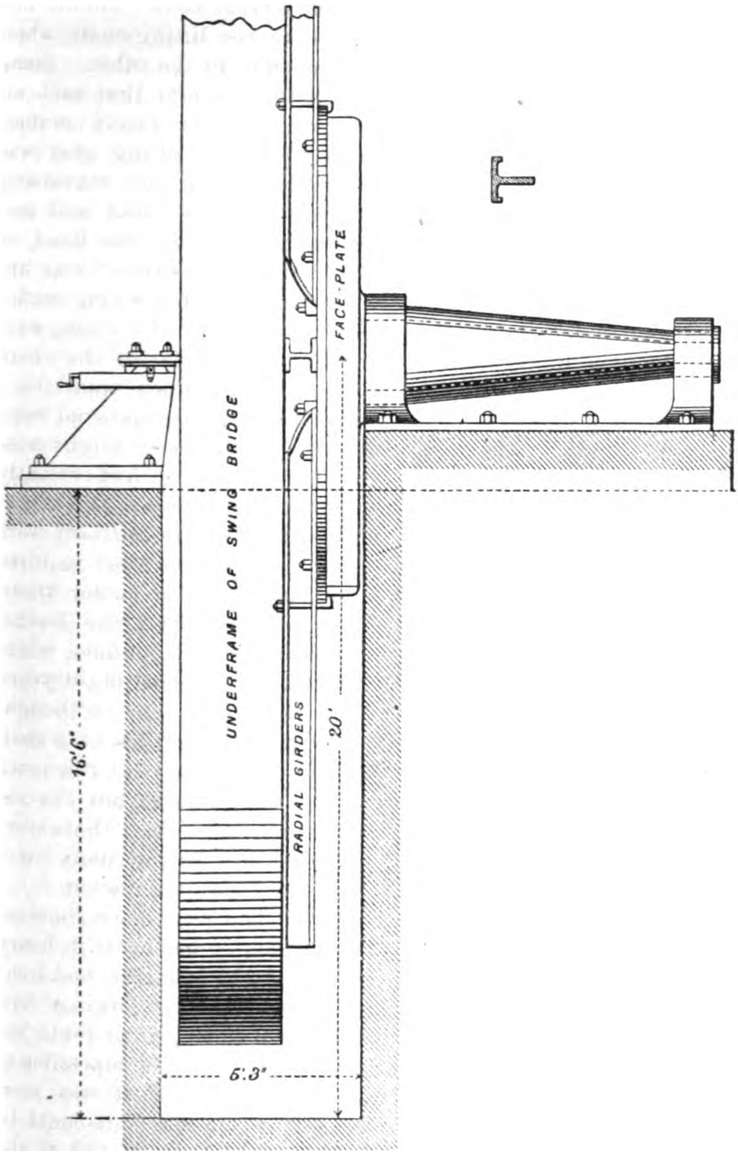
[1] Institution of Mechanical Engineers, Proceedings, 1864, p. 189. "On improvements in heavy tools for general engineering and iron shipbuilding work."

engineers, because they seldom combined them. He would suggest that a carefully prepared historical collection, showing the progress and development of machine-tools during the past half-century, would form a valuable addition to the Library of the Institution. Mr. Tweddell.

Mr. C. J. APPLEBY held that the users of machine-tools were largely indebted to the Author of the Paper and to his family for the sound practice in the construction of such machines, wherever they might be made. There could be no doubt that the large output, and the accuracy of the work produced by the tools which had been described, were highly necessary in these days of keen competition. Probably most engineers would like to substitute the types under consideration for their old machinery; but many could not afford to do this, and must thus work at considerable disadvantage. He believed he had seen some of the tools referred to by the Author, and, as regarded the 40-inch lathe, it was astonishing to see the mass of steel it removed—not fine turnings, the cut being so heavy that the whole of the metal removed was scrap fit for re-melting, and worth several pounds a ton more than ordinary turnings. As regards the crane, he thought the design did not compare favourably with that of the other labour-saving machines to which attention had been directed. A span of 30 feet seemed to him a short one for a 30-ton traveller; but even with this short span, the position of the driver at one end was unfavourable to the accuracy in working to be desired in erecting shops, where such machines were generally required. The tendency was to increase the width of shops where large work was produced, the width varying from 40 to 60 feet, or a little more—20 metres was a span of shops which had recently come under his notice several times. Of course, the inconvenience referred to increased with the width of the shop and involved more signalling than was desirable, especially if some large machine should be between the driver and the work he had to do. He preferred having the driver over his work where practicable, or in any case centrally in the span of the crane; he did not remember an instance where this could not be arranged, either by providing a platform along the whole length of the traveller-girder, or by one suspended from the crab. No doubt in foundries, melting-houses, &c., it was necessary that the driver should be at that end of the crane where he would be the least exposed to the fumes and heat arising from the floor; but even in that case, he thought it was better to have a platform below the traveller-girders than above, as shown in Fig. 21. There could be no doubt that friction clutches were the best means for Mr. Appleby.

Mr. Appleby. driving the traversing and travelling motions, and he believed the Author had been the first to use this arrangement. He did not see any provision for coiling and uncoiling the lifting-chain when the load was being traversed from one side to the other. Some experiments which he had made had convinced him that such an arrangement was most desirable, especially for heavy cranes. The power required to work the coiling and uncoiling gear was very small, whilst the coefficient of friction in the traversing motion was reduced by nearly 40 per cent., the wear and tear of the chain being also much less than when it was fixed, as indicated in the diagram. The "cup or capstan-drum" was undoubtedly an excellent device, and admitted of working under conditions which would be almost impossible if the chain were coiled on a barrel in the usual manner. The links of the chain could not become distorted as they often were when coiled on a barrel; but the great advantage was, that it was immaterial what length of chain was used. By way of illustration, he might refer to a crane made by him some years ago, which he had recently seen. It was of 15-ton power, and about 68 feet span, the height of lift varying from 10 to 265 feet. It had been in constant work for a long time, and neither chain nor any other part had required renewal. This crane was driven by rope, and the power transmitted by friction-clutches. The preference which the Author seemed to entertain for shaft transmission was well founded where there was much grit or dust. He had used it for about eight years, and during that time there had been no renewal; but he thought much might be due to the kind of bearings. The life of a shaft used in transmitting power for working cranes was of course much greater than that of the rope used for transmission; but the cost of the former was much higher than the latter, and there were other considerations which led him to think that, in many cases, the balance of advantage was in favour of rope-transmission.

Mr. Cowper. Mr. E. A. Cowper thought that the members were much indebted to the Author for giving this record of the improvements in heavy tools. The question was not simply one as between steel and iron: it was partly in reference to the large castings and forgings now in use, especially for marine purposes and guns, which could not be dealt with otherwise than by large tools. It was impossible to do good work with light and springy tools, and it was most expensive to attempt to do it, as only the lightest cuts could be taken, and even then the work was not true. In regard to the 40-inch lathe described in the Paper, the bearing was said to be 12 inches in diameter and 21 inches long. He did not take excep-



40-Feet Face-Plate Lathe.
1 inch = 5 feet.

Mr. Cowper. tion to the diameter, but he did to the length, for he did not think that the bearing would take the whole of the heavy weight at the front. He should make it rather larger in diameter and rather shorter in length. The improvement in the milling-machine was excellent. He noticed also, that in most of the descriptions of the tools tee-grooves were used. He quite approved of them, and had used them himself for many years. The use of the two screws for the sliding-carriage of the lathe was a new departure and a really good one. He did not agree with a previous speaker in thinking that they could not be worked together. Screws could now be made reasonably true. With reference to the circular cutters formed of tools fixed in disks referred to by the Author, they were not, he believed, put forward as new. Mr. Cowper had used them in different forms for forty years. He had had them 18 inches in diameter with twenty tools in them, and 4 feet 6 inches in diameter with forty or fifty tools. It was a tool that removed the metal very expeditiously, and was extremely useful for facing joints in large work. The annexed Fig. (p. 141) represented a lathe which he had made for a special purpose, namely, for turning 36-feet turn-plates and roller-paths for bridges, in about the year 1845. The lathe was driven with a friction-clutch, which he approved of for such tools, because when the machinery was going at full speed it was dangerous to start a lathe carrying 30 tons at once. If a heavy strap was put on carelessly, it was apt to give too much strain for the moment; but with a friction-clutch there was safety in case of anything jamming. The angle ought to be under 1 in 8. Then the machine started in a satisfactory manner without any jolt or jar. He ventured to turn the heavy cast-iron underframes of swing-bridges on it, such as the swing-bridge at Perth, and the Shannon bridge, &c. The weight hanging on the face-plate was about 30 tons in such cases, and about 36 feet or more in diameter over the angles, the pit being capable of taking an article 40 feet in diameter. It was a very cheap lathe. The mandrel was of cast-iron, 30 inches in diameter, and 12 inches long in the bearing, and the length 8 feet over the back-bearing; the face-plate had a key fitted into it, and the mandril, under the root of each rib on the face-plate, and this, he believed, gave great stiffness to the face-plate. The gearing had true epicycloidal teeth throughout, but not pitched and trimmed, and although the pitch circle of the gearing in the face-plate was only 12 feet in diameter, the motion was most steady, with two slide-rests and two goods cuts and a boring bar at work at once. He attributed this to the correct form and pitch of the teeth.

Mr. W. S. TOMKINS said he had some hesitation in criticizing the Paper, being a competitor of the Author's. He should have preferred to see the slide-rests of the lathe when turning the largest diameters better supported. It was evident that they would be considerably beyond the ribs of the bed, and would be so far ill-supported. In a lathe that he had constructed the bed was, he believed, formed of four distinct ribs placed at a much greater distance apart than in the Author's. He was much indebted to the Author for what he had said about heavy tools for heavy work, for it was evident that there must be tools of increasing weight to deal with the masses to be coped with. It was not in the hands of the tool-makers to fix the limit; it was their province to supply what was required. He greatly admired the ingenuity of the Author's constructions. There was of course no motion which a mechanic could not perform if required; but the question was whether it could be performed advantageously. As to the universal planing-machine, he did not think it worth while to perform all those separate operations in one machine. He understood the disadvantage of having to shift the piece operated on several times, but he did not think that the several operations could be advantageously combined. It was good mechanically, but it was bad commercially. Tool-makers had great difficulty in persuading purchasers of the merits of thoroughly good heavy tools. It was comparatively easy to make a good and substantial tool, but it was another thing to sell it. Like the Author, he should be always delighted to do his best to provide thoroughly substantial tools, and he had no doubt that between them they would be able to cope with anything that they might be called upon to deal with. Mr. Tomkins.

Mr. LOFTUS PERKINS said that reference had been made to the power required to cut steel. He had lately been using Whitworth metal. It seemed very soft, but it was very hard to work—twice as hard as iron, taking double the power. There was one tool which tool-makers wanted but had not had given to them—a planing-machine by which they could plane a screw. Latterly he had to make a screw-propeller and had tried to make it true. That could be done, he thought, with a machine like the Author's if, instead of having a movable table, he had the same table as the milling-machine—a planing-machine with the table of the slotting-machine. With that moulds of every description could be planed, which with ordinary machines could not be done. Messrs. Whitworth, who made the screws for him, had to plane them flat first and then bend them into shape. The only thing Mr. Perkins.

Mr. Perkins. approaching such a tool as he had mentioned was a wall planing-machine, which did not extend far enough to take in the large diameter.

Mr. Maudslay. Mr. HENRY MAUDSLAY remarked that the large face-lathe described by Mr. Cowper was similar to one that could be seen at Messrs. Maudslay Sons and Field's wharf—it had been designed and constructed by his grandfather, Henry Maudslay, who died in 1831. The principal bearing of the mandrel was 9½ inches in diameter, and it was solid. The diameter of the face-plate, or chuck, was 9 feet, and the depth of pit to the centre of the mandrel was 20 feet; it was used to turn the outer rim of fly-wheels for land-engines. There were two methods of driving this lathe. It was also used for boring, and had actually bored cylinders for steam-engines up to 10 feet in diameter, by placing a large boring bar between the heads. In fact, it was almost of a universal character. It was of great antiquity, it worked thoroughly well, and he believed that this lathe, having been at work day and night, had done more work than any existing lathe. With reference to the table of the large universal planing-machine (Fig. 8), there was shown an end view of the table moving along in grooves or portions of a concave or dished surfaces, which did not appear to him to give that amount of resistance sideways to the movement of the table, which a more frequent form of Λ-shaped bar would give. If chippings and dirt got into the groove form, they would remain there; but with a Λ-shape it was easy to put a lump of tow and oil in front of the traversing body, by means of which all the dust and dirt would be wiped off the four faces of the two guide-bars.

Mr. Carbutt. Mr. E. H. CARBUTT, M.P., said that Mr. Tweddell had asked when makers were going to stop making larger and larger machine-tools. He would answer it by asking another question. When were they going to stop making larger and larger steamboats, and requiring them to go faster and faster? During the last ten years the speed between New York and Liverpool had been increased from 15½ to 19½ knots per hour, and the size of the steamboats had increased 50 per cent. When it was remembered that that referred to one class of ships making four hundred voyages a year, almost without a break-down, it would be seen that some very good tools were required for work of that kind. He had been a little disappointed, knowing that the Author had come from Messrs. Whitworth, that he had not given some account of the hydraulic forging-press, which was no doubt the most valuable workshop tool. Although he was a steam-hammer maker, when

he first saw the hydraulic-press at work, he came to the conclusion that the days of the steam-hammer were gone. Very large forging-presses were being made in this country. He had recently seen one of 4,500 tons, which was calculated to be equal to a 150-ton hammer; and as there was nothing beyond a 25-ton hammer, it was evident that some large forgings would be made, and that some good tools would be required. He well remembered when a lad being taken round Messrs. Whitworth's by the Author, who explained to him that the tools showed the character of the men who designed them, as much as the bumps on their heads. That made a great impression on him at the time, and he was glad, after so many years, to find the Author still to the fore in designing workshop-tools. Mr. Carbutt.

Mr. W. Hulse, in reply, observed that Mr. Muir, who had opened the discussion, thought the bearing of the pinion which drove the face-plate with no cap to it was wrong in construction. The solid bearing was, however, preferred in these lathes on account of the exceedingly heavy work they had to do, and the consequent necessity of attaining the greatest possible rigidity in all the resisting parts. Several of such lathes were in use doing the work described in the Paper, and exemplified to some extent by the cuttings exhibited. As regarded the two screws in the combined boring-machine and lathe, which Mr. Muir would defy any one to make perfectly true, no such difficulty in doing this had been experienced by the Author, and as an example of such construction in every-day practice, the ordinary planing-machine might be mentioned, with its two screws and gearing for lifting and lowering the cross-slides. Of the "vertical and horizontal planing-machine," the table of which Mr. Muir thought extremely weak, upwards of thirty were in use, and the Author had not heard of any such complaint from the users. It was difficult to understand what was in Mr. Muir's mind when alluding to the Tay bridge. The vertical milling- and drilling-machine, considered by Mr. Muir an abortion, but pronounced excellent by Mr. Cowper, was in extensive and increasing use, and was appreciated for the steadiness of action referred to in the Paper. The employment of a long pinion obviated the necessity of one sliding on a shaft, which, owing to wear between the key and key-way, would soon give rise to slackness between the driving-strap and the cutter, to the disadvantage of the work both in quality and in quantity. No inconvenience had arisen in practice from the use of the long pinions, nor had they ever come to resemble "a crooked stick." Mr. Tweddell wished that something had been Mr. Hulse.

Mr. Hulse. said about the increasing size of machine-tools, and as to how far it was wise to go on increasing the size of castings and objects manipulated. The Author saw no sign that the limit of size of machine-tools had been reached. He thought tool-makers would be able to meet any demand for bigger tools. The system of constructing the larger pieces of the tools in parts securely joined together was now well understood, and met the question of transport. The castings and forgings manipulated by machine-tools could be, and were being, similarly constructed in parts, so as to meet the transport and other difficulties. Nor did it seem unwise to encourage increasing sizes, as long as they were in demand, especially as the so-called building-up system afforded such ready facilities. As regarded dealing with steel, the Author's experience was, that in every variety there was, compared with iron, a greater resistance to the cutting action, due to, and corresponding with, its tenacity and "temper"; and speaking generally he had found that working steel of average quality, with the machine-tools ordinarily used for iron, cost about double what it would on the stronger and more powerful tools, specially designed, as indicated in the Paper. He was much obliged to Mr. Appleby for his generous personal remarks. As regarded substituting the types of machine-tools under consideration, for old machinery, in the case of engineers with limited capital, he thought that such changes might be made gradually, by clearing out the lighter tools at first, retaining the medium ones, and putting in, from time to time, other tools of the strength, weight and power requisite for securing a large out-put combined with accuracy of work. As to the 30-ton crane, it was of course not the Author's fault that the shop was only 30 feet wide. Experience had shown that with a crane of this width, the driver, standing at one end of the traveller, worked the crane with facility and with the precision required in an erecting shop. In the case of a traveller 60 feet wide, the platform for the driver would be placed centrally in the span of the crane as suggested by Mr. Appleby; the arrangement of the hand-levers for working the friction-clutches being such that the levers might be situated at any point in the length of the traveller. The platform was not above the traveller-girders as supposed by Mr. Appleby; this would be seen on reference to the elevation (Fig. 20). No arrangement for coiling and uncoiling the lifting-chain when traversing the load had been introduced into the crane, and the Author would hardly have supposed that the advantages of such an arrangement could compensate for the additional cost and complication involved. In

deciding whether to use a shaft or a rope for transmitting power Mr. Hulse. to a traveller-crane, he would take into consideration the circumstances appertaining to each particular case; but his experience was, that in the long run, a shaft, where there was no special obstacle to its use, gave the most satisfactory and economical results. He appreciated the opinions expressed by Mr. Cowper with reference to the long front-bearing in the 40-inch lathe, as compared with the exceedingly short one shown by Mr. Cowper in the Fig., p. 142, of his own lathe. He would say that the increase in the length of such bearings had been going on for years. Both the diameter and the length were now made much greater than formerly, the latest proportions for a 40-inch lathe being a diameter of 13 inches and a length of 21 inches. The surfaces of both brass-bearings of the spindle were carefully scraped, so as to bear upon the spindle uniformly throughout, and their area was proportioned to suit the work to be done. Friction-clutches for starting heavy lathes were now infrequent, as the strap-shifting apparatus was improved so as to work the straps gradually from the loose to the fast pulley. Mr. Tomkins urged that the slide-rests in the 40-inch lathe would be insufficiently supported when turning the largest diameters. In answer to this, he would point out that the sliding-carriages of the lathe in question, being of deep section, and extending across the bed, gave adequate support to the slide-rests, even when they overhung the bed. As a matter of fact, however, the lathe being designed specially for objects of great length (and not of large diameter) such as guns and propeller-shafts, it was only seldom that the slide-rests were required to work in the overhanging position. The form of bed mentioned by Mr. Tomkins was like that of the 34-inch lathe, which was described in the Paper as having four longitudinal girders, and as being made of great width, so that the slide-rests never overhung the bed. In this case the sliding-carriages only extended partly across the bed. With reference to the universal planing-machine to which Mr. Tomkins referred, the Author thought it would not be questioned that in dealing with such objects as large engine and machine tool-beds, considerable advantage, in point of economy as well as in accuracy, was attained by performing several operations upon them at a single setting; and this practice was now being largely adopted. He was pleased to find that Mr. Perkins and he were agreed as to the large increase of power required in dealing with steel, as compared with iron, however soft the steel might appear to be; and he thanked Mr. Perkins for his hint as to further requirements in planing-machines. He was sure that tool-makers

Mr. Hulse. were prepared, as soon as a demand was manifested, to meet it to the best of their power. The 40-feet lathe mentioned by Mr. Maudslay, had been described by Mr. Cowper. He thought it could scarcely be regarded as illustrative of modern practice in machine-tools. The slide-surfaces of the planing-machine table were not concave or dished, as supposed by Mr. Maudslay, but of the usual V shape, the peculiarity being that the V was a very flat one, the angle enclosed measuring 150°. The lines of the diagram which appear to have misled Mr. Maudslay, represented brushes fixed at the ends of the bed, for removing oil from the table as it traversed along, and thus preventing it from dripping on the floor. He was gratified by Mr. Carbutt's observations, and had it been within the scope of the Paper, he would certainly have made mention of hydraulic forging-presses. The Paper, however, was restricted to dealing with machine-tools and workshop appliances, for manipulating heavy forgings and castings after they had left the forge, foundry, or melting house, as the case might be.

Sir F. Bramwell. Sir FREDERICK J. BRAMWELL, President, said that so thoroughly had the Author kept himself in the background, that had it not been for Mr. Hulse's great reputation, no one who had listened to his Paper could have gathered that he was a tool-maker and was commercially interested.

He could not on that the last occasion on which he should have the honour of presiding at an Ordinary Meeting, leave the Chair without expressing his gratitude to those who had attended the meetings during his Presidency, for the excellent manner in which they had, as a rule, spoken on the Papers under discussion, and had thus conveyed to the members knowledge which they did not previously possess; and he felt sure that when the Volumes relating to that period were referred to it would be found that they had not fallen off from the high standard of excellence previously attained. Nor could he leave the Chair without expressing that gratitude to those who had attended the meetings for their kindness to himself. If on any occasion it had been his duty to exercise the chairman's authority his ruling had been most readily acquiesced in, and he desired to thank most heartily all the members for the great indulgence he had experienced at their hands while presiding over these meetings.

Correspondence.

Mr. G. WILSON wished to point out, what he considered from his own experience to be a grave defect in the planing-machine, and that was the great distance between the uprights for carrying the saddle and the V slides on which the table moved. The overhang of wide and heavy work seemed to be, to judge from the design exhibited, in excess of that usually employed. The tool-boxes were made to travel, as was usual, to the ends of the saddle; therefore, it was fair to assume that, at times, work had to be planed of that width which only just cleared the uprights. This being the case it was impossible to plane a true and level surface, or to work strictly to the marking off; for when a cut was taken on the outside edge of wide widths, the table was sprung down, or canted, turning as on a hinge on the V slide nearest the tool. This "spring" or "cant" gradually decreased until the tool came over, or in between the V slides, when a dead cut was taken, without any spring at all (excepting that due to a long saddle which was almost imperceptible, and need not be taken into account with a well-made machine), consequently the planed surface was curved instead of being level transversely. Mr. Wilson.

There were numbers of machines in existence, some turned out by the best manufacturers, that could not plane a level surface, and chiefly for the reason above mentioned. In these machines the "spring" could easily be detected when a heavy cut was being taken, by the bevelled edge of the work, the tool striking on the mark, say, and then appearing to glide upwards, and dropping down again when it came off the material at the opposite end. This same defect also accounted for the "digging in," and "varying" planing, experienced with some machines, which was owing to the inequality of the material being worked, the table tending to right itself at the soft places, and again to give at the hard.

He would also mention that the V slides seemed to be too shallow, and he was afraid that a heavy side-cut would tend to displace the table more than if deeper V's were used. In the milling-machine the Author appeared to have carefully provided against any "spring" when working, by carrying the spindle in a sliding-trunk so that the tool was always well supported near the cutter. This was no doubt a good plan, and he thought the same idea should have been carried out with regard to the planing-machine, only that the work in this case should be as well supported as the tool.

Mr. Hulse. Mr. Hulse, in reply to Mr. G. Wilson, who urged that there was a grave defect in the planing-machine by reason of the great distance between the uprights for carrying the saddle and the V slides on which the table moved—a defect which, when planing at the outside edge of wide widths, would result in the table being sprung down or canted—stated, that although such consequences might be anticipated in planing-machines of light make, they were avoided in the one described in the Paper, by the table being made strong enough to prevent springing and heavy enough to prevent canting. The weight of the table was about 30 tons, and was sufficient not only to prevent canting, but also any lateral displacement, which might otherwise result from the shallowness of the V slides. These were made to contain the largest possible angle consistent with the requisite lateral stability of the table under the heaviest side cutting, in order to minimise friction. In using planing-machines of the proportions shown, the Author had experienced no difficulty in planing level surfaces, nor had he found any "digging in" or "varying" planing. The proportion of overhang beyond the V's in the planing machine described was approximately that which the Author adopted for large machines, say 7 feet wide and upwards. In smaller machines the overhang was less, and the table wider proportionately, this latter being in order to afford increased support to the wide objects which frequently came on such machines, and which objects were frequently not strong enough of themselves to resist the cut without springing. The increased width of the table in such machines also enabled a maximum number of separate objects to be fixed and planed at the same time.

ANNUAL GENERAL MEETING.

25 May, 1886.

Sir FREDERICK J. BRAMWELL, F.R.S., President, in the Chair.

The Minutes of the Annual General Meeting of 2nd June, 1885, were read and confirmed, and the Notice convening the present Meeting having also been read, it was moved, seconded, and resolved,—That Messrs. R. W. P. Birch, O. Brown, F. S. Courtney, J. M. Dobson, H. Faija, W. Matthews, C. S. T. Molecey, E. Perrett, H. S. Ridings, W. H. Thelwall, and R. H. Thorpe be requested to act as Scrutineers for the election of the President, of four Vice-Presidents, and of fifteen Other Members of Council for the ensuing year; and that, in order to facilitate their labours, the Balloting-papers should be removed at intervals during the hour the ballot remained open.

The Ballot having been declared open, the Secretary read the Report of the Council upon the general condition of the Institution and upon the proceedings during the Session 1885–86.

Resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings" in the usual manner.

Resolved,—That the best thanks of the members be accorded to the Vice-Presidents and other Members of Council for their assiduous and constant attention to the affairs of the Institution.

Mr. Edward Woods, the senior Vice-President, replied on behalf of himself and his colleagues.

Resolved unanimously,—That this meeting desires to record the high sense of its indebtedness to Sir Frederick Bramwell, F.R.S., President, for devoting so much of his valuable time and talents to promote in every way the efficiency of the Institution; and for the marked ability and genial manner with which he has conducted the business at the Meetings.

Sir Frederick Bramwell, F.R.S., President, expressed his acknowledgments for this resolution.

Resolved,—That the thanks of the Institution be presented

to Messrs. Hilary Bauerman and H. G. Harris, the Auditors, for the careful manner in which they have examined and audited the accounts; and that Messrs. H. G. Harris and E. Harry Woods be requested to act as Auditors for the ensuing year.

Mr. Hilary Bauerman returned thanks.

Resolved,—That the thanks of the members be given to Dr. William Pole, F.R.SS. L. and E., Honorary Secretary, and to Mr. James Forrest, the Secretary, for the able manner in which they have discharged the duties of their offices, and for their assiduous attention to the affairs of the Institution.

Mr. Forrest responded.

The Scrutineers then announced that the following gentlemen had been duly elected:

President.

EDWARD WOODS.

Vice-Presidents.

George Barclay Bruce.	George Berkley.
Sir John Coode.	Harrison Hayter.

Other Members of Council.

William Anderson, of Erith.	James Mansergh.
Benjamin Baker.	William Henry Preece, F.R.S.
John Wolfe Barry.	Sir Robert Rawlinson, C.B.
Sir Henry Bessemer, F.R.S.	Sir Edward James Reed, K.C.B., F.R.S., M.P.
Edward Alfred Cowper.	Francis Croughton Stileman.
Sir James Nicholas Douglass.	Sir W. Thomson, F.R.SS. L. & E.
Sir C. Douglas Fox.	Sir Jos. Whitworth, Bart., F.R.S.
Alfred Giles, M.P.	

Resolved,—That the thanks of the meeting be given to the Scrutineers, for the efficient manner in which they had discharged their task; and that the Ballot-Papers be destroyed.

REPORT OF THE COUNCIL, SESSION 1885–86.

HISTORICAL NOTICE OF THE INSTITUTION AND ITS PROCEEDINGS.

It is now exactly fifty years since the existence of The Institution of Civil Engineers was first announced to the world by the publication of its proceedings. It may therefore not be inopportune to submit to the members a condensed notice, tracing the various steps of its career, and explaining generally its present constitution and position.

The honour of having originated the Institution is often assigned to Smeaton, or to Telford, but the idea is erroneous in both cases. Smeaton died many years before it was thought of, and Telford only joined it after its establishment.

A Society of Engineers, still existing, was founded by Smeaton in 1771; it includes many of the most eminent members of the profession, but it is rather of the nature of a social club than of a scientific association, and has no connection with this Institution. It was indeed of too exclusive a nature to meet the wants of so large and mixed a body as soon became engaged in engineering; and early in the present century a feeling began to be entertained that an Institution on a larger scale, having for its object the furtherance of professional knowledge, might be made eminently useful.

The persons who took the initiative in the matter were six young men, then beginning their engineering life, William Maudslay, Joshua Field, Henry Robinson Palmer, James Jones, Charles Collinge, and James Ashwell. Towards the end of the year 1817, they, impressed with the difficulties of gaining the knowledge necessary for the diversified practice of engineering, resolved to form a Society for promoting regular intercourse between persons engaged in the profession, to the end that such persons might mutually benefit by the interchange of individual observation and experience.

The first formal meeting was held at the Kendal Coffee House, in Fleet Street, on the 2nd January, 1818. The proposal was favourably received; the Society was established; other engineers joined, and rules were framed for its government. During two years

it continued to meet, and the result of its experience of the value of the meetings was such as to warrant an effort being made to extend the limits of the Society. It was perceived that a principal step towards this extension would be to obtain the direct patronage of some eminent and popular professional man. Accordingly, on the 23rd of January, 1820, the following resolution was passed:—

"That in order to give effect to the principle of the Institution, and to render its advantages more general both to the members and the country at large, it is expedient to extend its provisions by the election of a President whose extensive practice as a Civil Engineer has gained him the first-rate celebrity;". . . . "and that a respectful communication be made to Thomas Telford, Esq., Civil Engineer, requesting him to patronize this Institution by taking upon himself the office of President."

So little was the Society known up to this time, that Telford had never heard of it when the foregoing resolution was announced to him; but appreciating, with characteristic judgment, the value of such an Institution, and the useful results it was capable of yielding, he accepted the proffered chair without hesitation, and was formally installed on the 21st of March following.

Telford's name gave an impulse to the progress of the Society, which grew rapidly in importance under his fostering care, until, on the 3rd of June, 1828, it received a Charter of Incorporation under the Great Seal, by the title of THE INSTITUTION OF CIVIL ENGINEERS. Telford died on the 2nd of September, 1834. A few years before his death he had begun to contract his engagements, and as he gradually withdrew from the toils of business, his attention became more and more concentrated on this Society. It was, indeed, the last object of his solicitude, and gave employment to his mind in the evening of his days. Its collections were enriched by his bounty, and when, full of years and of honours, he felt the close of life approaching, he endowed the Institution with the munificent bequest which has since done so much to encourage the production of Original Communications, for reading at the meetings and for publication in the "Minutes of Proceedings."

In 1835 the Chair was taken, in succession to Mr. Telford, by another engineer of acknowledged eminence, Mr. James Walker.

In 1836 the first Volume of the "Transactions" was published. It was a handsome Quarto of 325 pages, illustrated by 28 elaborate engraved plates, and it contained 28 selected communications, for the most part of high character, and written by men of considerable eminence. There were also added copies of the Charter

and subsidiary Regulations, with a list of members, and in the preface a short history was given.[1] From the data in this volume the state of the Institution at that time can be correctly ascertained.

According to the "Regulations," as they were then called, the Institution was declared to have been formed "for facilitating the acquirement of professional knowledge, and for promoting mechanical philosophy."

It consisted essentially of three classes:

1. MEMBERS, being persons engaged in the practice of Civil Engineering (those who lived out of London being called Corresponding Members).

2. ASSOCIATES, persons whose pursuits constituted branches of Engineering, but who were not considered as Engineers by profession.

3. HONORARY MEMBERS.

There were four Vice-Presidents: William Cubitt, Bryan Donkin, Joshua Field, and Henry Robinson Palmer; and seven other Members of Council, among whom were I. K. Brunel, Robert Stephenson, James Simpson, and John Macneill. The Secretary was William Gittins.

The Members were 140 in number, and among them are found the names of Bramah, Brunel (Senr.), Tierney Clark, Gravatt, Penn, Perkins, Seaward, Vignoles, Bidder, Bodmer, Buck, Fairbairn, Grainger, Thos. E. Harrison, Hick, Leather, Leslie, Locke, Murray, Aaron Manby, Rastrick, Rendel, Sopwith, Smith of Deanston, the Stevensons of Edinburgh, Nicholas Wood, Arthur Woolf, and others well known in the profession. The Associates (many of whom afterwards became Members) numbered 100, and the Honorary Members 14. The whole strength of the Institution was therefore 254.

In 1837 the publication of the smaller "Minutes of Proceedings," in Octavo, was commenced. This publication was at that time intended to give only Abstracts of the Papers, and of the discussions (or, as they were then termed, "Conversations") that took place thereon. The Papers themselves were submitted to the consideration of the Council, and a certain number were selected for publication in full in the Quarto form.

In the Report for 1837 (the first published) the Council dwelt with satisfaction on the increasing success of the Institution, and

[1] A second edition of this volume was published by Mr. Weale in 1842, but the book is now very scarce.

expressed a hope that the profession generally would unite in advancing the objects which the original projectors had in view.

During this year Mr. Thomas Webster, M.A., a well-known barrister, was appointed to the office of Secretary.

In the Report for 1838 the Council gave an account of some important changes which had, during the Session, been made in the By-Laws and Regulations, for the purpose of rendering them more definite and consistent with the Charter. The qualifications of Members and of Associates were modified, and the class of Corresponding Members was merged in that of Ordinary Members. A new class was formed under the name of "Graduates"; these were young men in course of education as Engineers, like the present "Students," but, differing from the course subsequently pursued with the Students, full corporate privileges were given to the Graduates—a step which afterwards led to much inconvenience.

The composition of the governing body was also altered. It had hitherto consisted (including the President and four Vice-Presidents) of twelve Councillors, chosen entirely from the class of Members, but it was thought advisable to add two selected from the Associate class, and one additional from the Member class, making the total number fifteen.

In the same year a Second Volume of Quarto "Transactions" appeared, on a similar scale to the first. It contained 20 Selected Papers, illustrated, as before, by 33 steel engravings.

The Institution at first occupied rooms hired at 15, Buckingham Street, Adelphi. In 1834 a small house was taken, at No. 1, Cannon Row, Westminster, but as the numbers increased the accommodation was found to be too limited. It was then attempted to obtain from the Government, as other scientific societies had done, apartments in Somerset House, but fortunately this application was unsuccessful, and suitable premises had to be sought elsewhere. It happened, just at this time, that a house was found in perhaps the most appropriate situation that could have been selected, and at Christmas, 1838, the Institution entered upon the premises it now occupies in Great George Street, where a meeting-room, about 30 feet square, was built in the rear of the front house. Although the expenses attending the change were, for the then moderate income, somewhat onerous, the difficulty was met by the members, who, when appealed to, answered the call very liberally.

In the Session 1839–40 some further alterations were effected in the By-laws, the chief one being that the total number of the

Council was increased to seventeen, of whom two were selected from the class of Associates as before.

During this Session there was an important change regarding the office of Secretary. It appeared to the Council that the increasing business was such as to require the whole and undivided time and attention of a properly qualified gentleman to fill this position as a paid officer, and it was taken on this condition by Mr. Charles Manby, who entered upon the duties at Midsummer, 1839.

In 1842 a Third Quarto Volume of "Transactions" was published, and this was the last that appeared. A fourth volume had been contemplated, but on account of the great cost attending this form of publication, the Council deemed it right to refer the subject to a Committee for consideration. The report of this Committee, mentioned in the Report of the Council for the Session 1845, represented that the quarto form, with elaborate plates, was found, as it had been in other societies, too expensive; that the selection of certain Papers, to the exclusion of others, might be considered invidious; that the delay in the publication of the Papers was prejudicial to the interests of the Authors, and had prevented many valuable communications from being read at the meetings; and that the character of the quarto volumes prevented their circulation from being as extensive as was consistent with the objects of the Institution. These and other arguments appeared conclusive against the continuance of the double form of publication; and it was decided that from the 12th of March, 1844, the Papers should be published in octavo in full, or with only such curtailment as could be practised without injury to the Authors' views, and that such illustrations should be given as were necessary. In this way the publication of the Minutes of Proceedings has been regularly continued, and they contain, in their long and ample series of volumes, now numbering eighty-four, a full account of the progress of the Institution, and of the matters which have engaged attention at the Ordinary Meetings.

At the end of the year 1844, an alteration was made which materially influenced the future of the Institution; this was a change in the duration of the Presidentship. Mr. Walker had occupied the chair since the death of Telford, a term of ten years, and, although the regulations required annual election, there was an implied understanding that the appointment was a permanent one. It had, however, been forcibly represented to the Council that a shorter period for the tenure of the office of President,

and of the other posts in the Council, would be advantageous. The question was fully discussed at a meeting on the 23rd of December, and, in consequence of resolutions then passed, a communication was addressed to Mr. Walker, which led to his objecting to be put in nomination again for the office of President. Notwithstanding this, however, at the Annual General Meeting on the 21st of January, 1845, Mr. Walker was chosen; but on his declining to serve, the meeting was adjourned till the 27th, when Sir John Rennie was duly elected, taking his seat at the next Ordinary Meeting on the 4th of February.

On the 6th and 27th of January, 1846, Special General Meetings were held, at which the change regarding the Presidentship was incorporated in the By-laws. It was enacted that in future no Member should be nominated by the Council for election to the office of President more than two years consecutively, and that at the expiration of such two years he should not be re-eligible for three years.

At the same time the qualifications of candidates for admission were more accurately defined, those of Members being made somewhat more strict, while those of Associates were widened, so as to comprehend a larger range of individuals. The corporate privileges of the class of Graduates were now curtailed. They were prohibited from voting at the elections of the Council and Officers, or from taking any active share in the direction and control of the affairs of the Institution. In fact, it was virtually decided to allow this class gradually to become extinct; no other elections into it took place, and some years later the remaining Graduates were transferred to other Classes. It was arranged to admit young engineers as Associates, from which class they could subsequently be transferred to the grade of Members.

It had been found during this Session that, owing to the increase in numbers, and to the consequent larger attendance at the meetings, the accommodation was insufficient. On the 28th July, 1846, a Special General Meeting was held, to consider some plan of meeting the difficulty. A Report of the Council having been read and discussed, inquiries were ordered to be set on foot to obtain a site on which to erect a building suitable for the wants of the Society. At an adjourned meeting, held on the 11th of August, a second Report of the Council was received. It stated the impossibility of finding a piece of ground possessing the advantages of the present situation, except on terms which it would be unwise to entertain. It was therefore decided to enlarge the meeting-

room, and to make such other alterations in the existing building as should render it more convenient for the purposes of the Institution. These works were carried out during the recess, at a cost of £4,350. To meet this outlay, it was arranged that every Member should subscribe £7 7*s.*, and every Associate £4 4*s.*, and that new Members and Associates should enter into an obligation to contribute like sums to form a "Building Fund" for defraying future expenses of the same kind. In the meantime Debenture Bonds of £100 each were issued to the extent of £2,500 to provide for the immediate requirements. Some of these bonds were afterwards voluntarily cancelled, and in other cases the holders, or their nominees, were placed on the books as Life Subscribers, in consideration of their surrender, so that in one way or other the whole of the bonds have disappeared.

A Special General Meeting was held on the 3rd of May, 1855, in compliance with a formal requisition, to consider propositions for making certain changes in the constitution of the Council, such as causing a certain number of the Members of Council to retire every second year. But after full discussion, these propositions were withdrawn.

In June 1856, Mr. Manby, who had held the post of Secretary for seventeen years, tendered his resignation, having accepted a professional engagement which prevented his devoting the necessary attention to the work of the office. He agreed, however, to continue to act gratuitously, and subsequently was appointed Honorary Secretary, a position he held till his death, on the 31st of July, 1884. The present Secretary, Mr. James Forrest (who had been for fourteen years more or less intimately connected with the Institution, in which he was to some extent brought up) was appointed Assistant Secretary at Midsummer 1856, his position being changed to that of Secretary on the 3rd of January, 1860.

In the course of 1866 the Council was led to consider the possibility of allowing engineering students to benefit by access to the Institution, a subject which had been in abeyance since the virtual abandonment of the class of Graduates in 1846. The Council thought that the object might be accomplished by the establishment of a class similar to the former Graduates, but with certain modifications; and brought the subject before a Special General Meeting, with a view to the necessary provisions being made in the By-Laws. This Meeting was held on the 26th of June, 1867, when the proposed alterations were passed, the essence of the provisions being, that the members of the new class, though

attached to the Institution and enjoying many special privileges, should have no corporate rights, and should only be admitted by, and remain Students during the pleasure of, the Council. The class was accordingly constituted, and, under the arrangements adopted, has been entirely successful.

Even before this decision was arrived at, it had been found that the accommodation was insufficient, and at the Annual General Meeting, on the 19th of December, 1865, it was resolved—

> "That the new Council be requested to mature a plan for providing additional accommodation for carrying on the business of the Institution, and to report to a Special General Meeting at the earliest opportunity."

Acting upon this Resolution, the subject received the constant and serious consideration of the Council. Various sites were examined and investigated, among others, that of the existing premises. The result was the recommendation of the purchase of Nos. 15 and 16 Great George Street (which happened then to be available), and the erection on that site of an entirely new building. It was pointed out that these two houses covered an area about twice as large as that of the house then occupied, that the situation was admirable, and that it had the peculiar merit of three open frontages. Also, that the cost of this proposal for acquiring the freehold, and for erecting and furnishing the building, would amount to about £66,000, a cost which it was proposed to defray partly by private subscriptions, partly out of the funds, and partly by raising money on mortgage.

Two Special General Meetings were held on the 5th and the 26th of June 1866, for the purpose of receiving the Report (of which the above is the substance,) upon the building question, when it was decided that the consideration of the subject be not further proceeded with, and that the Subscription List—which amounted to about £25,000—should be withdrawn and cancelled.

The matter was then allowed to remain in abeyance for a short time; but the Council elected in December 1867, presented a Report to a Special General Meeting held on the 7th of April, 1868, in which two projects were described and contrasted. One of these was the enlargement of the then existing premises in Great George Street, the other was the acquisition of an entirely new site on a vacant piece of ground in Victoria Street, which, like the one formerly proposed, had the advantage of three open frontages.

The proposition for enlarging the building on the existing site, with the addition of the back part of the adjacent house, No. 24, was adopted, and the meeting gave authority to the Council to enter into arrangements for a lease of ninety-nine years for each of those premises, and to proceed with the rebuilding according to the designs that had been prepared. The works were executed during the ensuing recess, forming the building essentially as it at present exists. The cost, inclusive of furniture, amounted to between £17,000 and £18,000. To meet this expenditure, the Council decided, in the first instance to dispose of the "Building Fund," next to realize the unconditional bequests, and lastly, to sell so much as might be required of the Institution Investments. This still left stock of the nominal value of about £3,000 to provide for future contingencies.

It should be stated that the freehold of No. 25, Great George Street, might have been acquired for £12,000, and that of the back part of No. 24, Great George Street, for £4,166 13*s*. 4*d*.,[1] but the Council decided not to purchase. The rent of the former, which had been £375 per annum, was increased to £450 for a term of 99 years, being at the rate of $3\frac{3}{4}$ per cent. on the purchase money, that of the other being £208 7*s*. for a like term, or 5 per cent. on its value as above.

In the Report of the Council presented at the Annual General Meeting in December 1868, it was stated that an inquiry had been instituted into the systems of engineering education (other than military engineering) in different countries; the cost to the students and to the respective governments, and the effect, or presumed effect, of such preparatory training on the profession. Data had been collected from various sources, and the work of arranging and comparing them was entrusted to Dr. William Pole, F.R.S. The result was the preparation of an Octavo volume on "The Education and Status of Civil Engineers in the United Kingdom, and in Foreign Countries," which was published by the Institution in 1870.

In the Session of 1871 a numerous body of members proposed that the number of the Council should be increased to twenty (the maximum permitted by the Charter), and that a broader basis of election should be adopted. Two Special General Meetings were held, at the first of which the proposed increase was carried, and

[1] The estimated value was £7,000, but Mr. G. R. Stephenson gave to the Institution his share of one-third, and Mr. Bidder £500 in diminution of his share also of one-third.

at the second it was resolved to alter the mode of preparing and printing the balloting lists.

Two years afterwards it was suggested that absent members should have the power of voting for members of Council by voting papers; but it was found that, apart from the merits or otherwise of the proposal, such a proceeding would be inconsistent with the provisions of the Charter. The suggestion was renewed in 1883, with the same result.

In the Report for 1873, the Council foreshadowed some important extensions and improvements in regard to the publications of the Institution. These were matured and carried into effect in the following year, and were described in the Report presented at the Annual General Meeting in December 1874.

For many years the "Minutes of Proceedings" of each Session had been contained in one Octavo Volume; but as the Papers and discussions had been gradually increasing, it became necessary, in the year 1870, to issue two volumes for each Session.

Three years later, it was thought desirable to introduce some material extensions. Hitherto, only those Papers were printed which had been read and discussed; but these were necessarily limited in number, and many communications were received which, though they could not be brought forward at the meetings, were yet of such importance as to demand publication. And indeed, the Council had at various times expressly invited the members to send in "engineering notes" on any topics of professional information which might be useful to their brethren; and many such were frequently received. It was accordingly decided to add to the Minutes a second section, for communications not read at the meetings, to be called "Other Selected Papers." This was commenced in vol. xxxix., being the first part for the session 1874–75, and has been highly appreciated.

At the same time a further addition was determined on, which, though it involved a great change in the established usage, was recommended by the benefits which had attended its practice in other societies; namely, the organization of a scheme by which the Minutes should contain a summary of information, gathered from the transactions of foreign engineering societies and from foreign scientific periodicals, on all branches of professional knowledge, so as to afford a perfect record, however brief, from year to year, of the progress of engineering science. This scheme was carried out, giving rise to the third section of the Minutes, entitled "Abstracts of Papers in Foreign Transactions and Periodicals." The Minutes were then enlarged to four volumes annually, brought

out at as nearly equal intervals as circumstances would admit, but always in advance of the succeeding Session.

These changes necessarily involved a great increase of expense, not only for printing and engraving, but also for a staff of abstractors (thirty or forty in number) and for some addition to the Secretary's staff; but it was considered to be justified by the services that would be rendered to the members and by the fact that the funds were sufficient to support the expense.

In December 1878, an alteration, or rather an amendment, of much importance was made in the Constitution of the Society.

Since the extinction of the class of Graduates, the Institution had consisted essentially of two classes, called "Members" and "Associates." The persons composing the latter class were defined to be "not necessarily Civil Engineers by profession, but whose pursuits constitute branches of Engineering, or who are by their connection with Science or the Arts, qualified to concur with Civil Engineers in the advancement of professional knowledge." It was the custom to confine the admission to the class of Members to persons who had acquired some eminence and standing in the profession, and to place young practitioners in the Associate class till they were considered qualified for the higher one, when they were "transferred." But many of the Associates thought it a hardship that they should be called by a name which did not imply full fellowship, and should be classed with persons "not necessarily Civil Engineers." This complaint had been noticed in the Report of the Council presented in December 1874, when it was suggested that some change might be advisable. Two years later, the matter having become more urgent, a scheme was submitted which, however, was negatived at a Special General Meeting on the 25th of April, 1877. The new Council, on their election at the end of that year, prepared, with legal assistance, another set of proposals, which with slight modifications were agreed to, and were incorporated in the By-laws, on the 2nd of December, 1878. This fixed the present Constitution of the Society, which is, that the Corporation consists of Members, of Associates entitled to the privileges of Corporate Membership, and of Honorary Members.

It was further provided that every candidate for election into the class of Associates entitled to the privileges of Corporate Membership should have been regularly educated as a Civil Engineer, and should be actually engaged in the design, or in the construction of such works as are comprised within the profession of a Civil Engineer as defined by the Charter; and that

only those Associates on the Register at the date named who were Civil Engineers by profession, and those thereafter elected as Corporate Associates, should be regarded as Associate Members. The class of simple Associates was retained, but without corporate rights.

In the year 1879, Dr. (afterwards Sir William) Siemens, Member of Council, offered a sum of £10,000 to form the nucleus of a fund for providing a suitable building wherein the Applied-Science Societies might be assembled under one roof. This munificent offer called forth warm expressions of gratitude; but the difficulties in carrying out such a comprehensive scheme, and at the same time of preserving the individuality and the property of each society, were so great, that the idea had to be abandoned. It had, however, long before been pointed out, and was still fully acknowledged, that there would be great advantage in bringing the many societies formed for the study of various branches of Engineering into closer union with this, the parent Institution.

In the Report for 1880, the Council alluded to the existence of a general feeling that it would be desirable for a President in future to hold office for one year only, and that the practice of nominating the same person for two years consecutively should be discontinued. In consequence of this feeling, the then President, Mr. William Henry Barlow, F.R.S., intimated that he did not wish to be proposed for President a second time. Since that date there has been an understanding that the Presidents should hold office for one year only, although there has been no change on the subject in the By-laws.

Of late years a new element has been introduced into the proceedings. About 1868 it was proposed that some measures should be taken for the improvement in professional knowledge of the Students by the establishment of "Readerships" in particular branches of Engineering. The idea was, however, not carried out. In August 1879, the expediency of instituting, in addition to the Ordinary Meetings, Lectures on special subjects of Engineering was mooted. But it was only in March, 1882, that the Council resolved to arrange for a limited series of Lectures, to be delivered by men of eminence, not on the elementary subjects of the Class Room, but on the principles involved in the action of "the Great Sources of Power in Nature," and their practical applications.

Accordingly, in 1883, six lectures were delivered "On the Practical Applications of Electricity;" which were followed in

1884 by others on "Heat in its Mechanical Applications;" and in 1885 by those on "The Theory and Practice of Hydro-Mechanics." Each of these series has been published in a separate volume.

In January, 1885, Dr. William Pole, F.R.S., M. Inst. C.E., was appointed Honorary Secretary in succession to Mr. Manby.

On the 28th of April, 1885, a Special General Meeting was held, chiefly for the purpose of altering the date of the Annual General Meeting. This had formerly been held in the latter part of December, but that period had been found inconvenient, and it was altered to the close of the Session.

Having now traced the steps by which the Institution has arrived at its present position, it may be desirable to give some account of its constitution, of the objects for which it was established, and of the way in which those objects are sought to be carried out.

CONSTITUTION.

The persons for whose benefit the Society has been formed are defined by its chartered title THE INSTITUTION OF CIVIL ENGINEERS. As the exact meaning of the words "Civil Engineers" is very important, and has given rise to much discussion, the Council considers it desirable to state the sense attached to them by the Institution.

The Charter defines "the profession of a Civil Engineer" as "The art of directing the Great Sources of Power in Nature for the use and convenience of man," and some examples of this definition are given. But it was pointed out by Thomas Tredgold, who drew up the "Description of a Civil Engineer," partly embodied in the Charter, that "the scope and utility of Civil Engineering will be increased with every discovery in philosophy, and its resources with every invention in mechanical or chemical science." Consequently, since the Charter was drawn, the range of practice of the profession has become much enlarged.

Thus the practitioners in this art may now have to do with many classes of works; for example:—

1. Works for facilitating and improving internal communications —as roads, railways, tramways, navigation by canals and rivers, bridges, and telegraphs of various kinds.

2. Works connected with the sea-coast, and for facilitating communication between the sea and the land, such as harbours, docks, piers, breakwaters, sea-walls, lighthouses, &c.

3. Works for facilitating communication across the seas; including naval architecture, iron shipbuilding, and the construction and laying of submarine telegraph cables.

4. Works for the reclamation, irrigation, or drainage of land; and for the prevention or the regulation of floods, including the improvement of rivers as arterial drains.

5. Works for cities and towns, such as sewerage, water supply, lighting, and street improvements.

6. Large and massive buildings generally, in their scientific and mechanical arrangements.

7. The operations of mining and of metallurgy, so far as they involve the application of mechanical science.

8. The design and construction of the mechanical prime-movers —such as steam-engines, water-wheels and other hydraulic motors, windmills, electric and other engines.

9. The design, construction, and adaptation to practical use of machinery and mechanical appliances of all kinds.

10. The design and manufacture generally of all large and important metallic structures, including artillery, and other large munitions of war.

This is a comprehensive but by no means complete catalogue, and if an estimate is attempted to be formed of the work done under it during the last century, and of the effect this work has had on the development of trade and commerce, on finance, on government, on every branch of industry, and indeed on every possible aspect of human interest, it must be admitted that the profession of Civil Engineering has become truly a great power.

It is important to define accurately what is meant by the prefix "Civil."

There has sometimes been a disposition to confine the word "civil" to those who practise in works of building and earthwork construction, such as railways, roads, harbours, docks, river improvements, and so on, to the exclusion of engineers who are engaged in some of the other branches of engineering enumerated.

There is no authority or warrant for such a limitation. The meaning of the word "civil" is quite clear when the history of the profession is borne in mind.

The earliest application of the term "Engineer" was to persons in military service, and down to a comparatively recent period it was only known in this application. But when the construction of public works in England for civil purposes began to take a large development, their designers, finding their work analogous

to that of military engineers, adopted the same term, using the prefix "civil" to distinguish them. There is reason to believe that Smeaton was the first civil constructor of large public works who called himself an engineer, and who used accordingly the distinguishing compound title.

The term "Civil Engineer" means, therefore, an engineer who is a civilian, as distinguished from a military engineer.

This Corporation is intended to include all classes of engineers who do not belong to the military service.

The remark has sometimes been made that officers of the Royal Engineers and of the Royal Artillery might complain of their exclusion from corporate rights in this body. Such a complaint would be as unreasonable as it would be for a Civil Engineer to complain of his exclusion from the privileges of Chatham or of Woolwich; and it must always be recollected that the Institution is able and most willing to welcome, and to attach to its body, in the Class of Associates, individuals whose pursuits and knowledge are akin to its own.

To comply, therefore, with the wording of the Charter and the spirit of the Institution, those constituting the body corporate must be persons actually following the profession of a Civil Engineer; and these may be, First, MEMBERS, persons who are of considerable standing in the profession; secondly, ASSOCIATE-MEMBERS, persons who are of less standing, but who may be transferred to the superior grade whenever they become qualified. HONORARY MEMBERS, who are persons of distinction, enabled to render assistance in the prosecution of Public Works, are also given corporate privileges as a matter of courtesy.

There is also, as already alluded to, the important class of ASSOCIATES, attached to the Institution, but without corporate rights. These are persons not Civil Engineers by profession, but who, by connection with Science or the Arts, or otherwise, are qualified to concur with Civil Engineers in the advancement of professional knowledge. The Council has thought it expedient to raise the standard of this attached class, and with this object to recommend for election only such persons as are distinguished in their particular walks of life. Into this class eminent scientific men, contractors, railway managers, military engineers, architects, and others, are gladly received.

There is also the class of STUDENTS; those composing this class are allowed certain special privileges, and may remain in it until they become eligible by age for admission as Associate Members.

Every member of the Institution has the right to append to his

name a certain abbreviated designation corresponding to the class to which he belongs.[1]

The Members, Associate Members, Honorary Members, and Associates are elected (their classification having been previously determined by the Council) by the ballot of the general body; the transfer from the grade of Associate-Member to that of Member is effected by the Council, by whom also the Students are admitted.

The Roll of the Institution.

The numbers of members of different classes at intervals of ten years are shown in the following Table:—

Date.	Honorary Members.	Members.	Corresponding Members.	Associate Members.	Associates.	Graduates.	Students.	Total of all Classes.	Actual Increase.
1836	14	45	91	..	88	..	..	238	
									362
1846	35	207	..	..	314	44	..	600	
									197
1856	26	289	..	..	466	16	..	797	
									542
1866	20	541	..	..	771	7	..	1,339	
									1,505
1876	14	864	..	..	1,582	..	384	2,844	
									2,256
1886	20	1,542	..	2,111	501	..	926	5,100	

Contributions to the Funds.

The following Table shows the rates of Annual Subscription—those persons being considered residents whose place of business or whose residence is within 10 miles of the General Post Office, London:—

	Member.			Associate Member and Associate.			Student.		
	£	s.	d.	£	s.	d.	£	s.	d.
Resident	4	4	0	3	3	0	2	2	0
Non-Resident . .	3	3	0	2	12	6	1	11	6

Every new Member and Associate, on admission, has to pay a fee of ten guineas; but no payment, other than the increased annual subscription, is due from an Associate on his transfer to Membership.

[1] The use of the simple letters "C.E." is expressly discountenanced by the Institution, as not founded on any qualification, and as being calculated to mislead.

			£
In 1836, the receipts	from all sources	amounted to	713
„ 1846	„	„	1,771
„ 1856	„	„	2,018
„ 1866	„	„	6,717
„ 1876	„	„	11,177
„ 1886	„	„	19,945

In the year 1860 the first investment was made on Capital Account, being the sums derived from Life Compositions (in lieu of annual subscriptions) and from Fees on entrance, neither of these receipts being considered in the light of annual income. The practice has since been regularly continued, and has resulted in the Institution at present being possessed of Stocks of the nominal, or par, value of £57,000, their market value being about £66,000. During this period the Life Compositions and Admission-fees together realized £50,045, while the unconditional bequests amounted to very nearly £8,988.[1] The cost of rebuilding the premises in 1868 has therefore been practically paid for out of income, although there had been no increase in the annual subscriptions since they were fixed in December 1837.

The premises are insured in the Guardian Fire Office for £12,000, and the other effects in the Sun Fire Office for £20,000.

Management.

The affairs of the Institution are managed by a Council consisting of twenty persons, viz.:—

One President, 4 Vice-Presidents, and 15 other members.

These are elected at the Annual General Meeting, and by custom, from the class of "Members," although according to the By-laws all Corporate Members are eligible.

The President may hold office for two years in succession; but, as already stated, it has become lately the custom for him to retire after the first year, when the senior Vice-President in duration of office is nominated in the balloting list to fill his place.

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[1] These Unconditional Bequests were as follows:—

		£	s.	d.
1860.	Robert Stephenson Bequest	2,000	0	0
1862.	Miller „	2,000	0	0
„	Errington „	1,000	0	0
1864.	Botfield „	28	0	0
1868.	Locke „	2,000	0	0
1869.	Burnell „	10	10	0
1870.	Appold Bequests	1,800	0	0
1880.	Napier Bequest	99	19	0
1883.	Beattie Legacy	49	2	9
		£8,987	11	9

At the Ordinary Meeting next but one before the Annual General Meeting, the Council are required to present a list of persons whom they nominate as suitable for the various offices in the Council for the ensuing year, and this list has to be distributed to the members eight days before the day of election. In the preparation of the balloting-list, it is sought to make it representative of every branch of engineering, and, as far as possible, of every influential centre of engineering. Irrespective of the President and the four Vice-Presidents, the list, in accordance with the By-laws, contains the names of twenty-four members, while only fifteen have to be returned; but it is competent for the electors to substitute any name or names for those included in the list, provided such substituted names are those of Corporate Members.

There are also two Auditors appointed by the Annual General Meeting, while the Treasurer and the Secretaries are appointed annually by the Council.

The following is a list of the Presidents to the present time:—

1820–34	Thomas Telford.
1835–45	James Walker.
1845–48	Sir John Rennie.
1848–50	Joshua Field.
1850–52	Sir William Cubitt.
1852–54	James Meadows Rendel.
1854–56	James Simpson.
1856–58	Robert Stephenson.
1858–60	Joseph Locke.
1860–62	George Parker Bidder.
1862–64	John Hawkshaw.
1864–66	John Robinson McClean.
1866–68	John Fowler.
1868–70	Charles Hutton Gregory.
1870–72	Charles Blacker Vignoles.
1872–74	Thomas Hawksley.
1874–76	Thomas Elliot Harrison.
1876–78	George Robert Stephenson.
1878–80	John Frederic Bateman.
1880	William Henry Barlow.
1881	James Abernethy.
1882	Sir William George Armstrong.
1883	James Brunlees.
1884	Sir Joseph William Bazalgette.
1885–86	Sir Frederick Joseph Bramwell.

The following Members (in addition to those who became Presidents) have served on the Council at various periods since 1836:—

Bryan Donkin, Henry Robinson Palmer, Francis Bramah, Isambard Kingdom Brunel, George Lowe, Sir John Macneill, William Alexander Provis, William Carpmael, Joseph Miller, Josiah Parkes, Thomas Wicksteed, Alfred Burges, Samuel Seaward, Robert Sibley, William Tierney Clark, George Rennie, John

Taylor, Francis Giles, William Chadwell Mylne, Benjamin Cubitt, Thomas Sopwith, Joseph Cubitt, Charles May, John Edward Errington, John Scott Russell, John Penn, Sir Joseph Whitworth, Bart., Nicholas Wood, George Willoughby Hemans, John Murray, Nathaniel Beardmore, Edward Woods, George Barclay Bruce, Sir William Siemens, George Berkley, Sir John Coode, William Pole (now Hon. Secretary), William Baker, George Fosbery Lyster, William Froude, Sir Isaac Lowthian Bell, Bart., Harrison Hayter, David Stevenson, Alfred Giles, Sir Robert Rawlinson, Edward Alfred Cowper, Sir Charles A. Hartley, Sir William Thomson, Alexander Meadows Rendel, Benjamin Baker, Sir Jas. N. Douglass, John Wolfe Barry, Sir Henry Bessemer, Sir Douglas Fox, William Henry Preece, Sir E. J. Reed, Francis Croughton Stileman, and James Mansergh.

The Sessions and Meetings.

The Session commences in November and ends in the following May.

During this time Ordinary Meetings are held on every Tuesday evening. At these meetings the Papers selected by the Council, from the large number sent in, are read and discussed, the discussions often extending over several evenings. A short-hand writer is in attendance who takes full notes of the discussions, and the whole, after proper correction, are printed in the Minutes of Proceedings.

In order to facilitate the discussions, proof copies of the Papers are supplied to any persons, whether members or not, who are supposed to be specially conversant with the matters treated.

It has often been found that persons unavoidably absent have wished to make remarks, and the Council has therefore authorized them to communicate such remarks to the Secretary, when they are printed, with the discussions, under the head of "Correspondence."

Students' Meetings.

To encourage the Students, Supplemental Meetings have been established, at which Papers prepared by the Students are read and discussed, some Member of Council or other prominent Member taking the Chair, but with this exception only Students are permitted to be present. These meetings have answered very well, and have fostered a wholesome spirit of emulation. Some of these Papers have shown great merit, and have been published in the Minutes of Proceedings.

As it is impracticable for Students in the provinces to take advantage of the meetings of their class in Westminster, local Associations have been established at Glasgow, Liverpool, Manchester, and Hull, so that some of the non-resident Students may have opportunities of meeting one another and of discussing professional subjects.

Minutes of Proceedings.

These have been already generally described.

The Proceedings for the Session 1884–85 comprised four Octavo Volumes, containing together 1,855 pages, and illustrated with 41 plates and 236 cuts in the text. Of these 929 pages were devoted to the Meetings, 509 to other Selected Papers, and 417 to Abstracts from Foreign Periodicals.

Copies of the Minutes are sent post-free, to every member of every class, wherever resident, and 185 copies are presented to other Institutions and Public Libraries in various parts of the world.

They are not published in the ordinary sense, and are therefore not on sale to the public.

The cost of the Proceedings for 1884-85, including postage, was about £6,500.

It should be added that not only is each volume furnished with a proper Index, but that General Indexes, extending over a large series of volumes, have been prepared, with much care and labour. These are arranged both for subjects and names, so that any subject contained in the Minutes can be at once referred to, and the name of every writer of a Paper, as well as of every speaker in the discussions, is also classified, along with the subject-matter of his essay or his remarks. This facility of reference gives a largely increased value to the Minutes of Proceedings.

House and Library.

The present house contains a handsome Meeting-Room, 60 feet long by 40 feet wide and 30 feet high, which will accommodate 450 persons. Below this there are a spacious Reading and Writing Room—where all English and foreign periodicals likely to be interesting to the members will be found—and a Council Room. The front of the house is chiefly devoted to the Library and to the offices of the staff.

Although the Meeting-Room is fairly large enough, except on extraordinary occasions, this cannot be said of the Library, where many of the books are inaccessible at short notice. The office-accommodation is also very insufficient and unsuitable for the ever-increasing business, and all that there is has to be utilized on meeting-nights for the subsidiary purposes of the meetings.

The Library is a feature of which the members have just reason to be proud. Originating with a present of books from Telford, on his accepting the Presidency, it contained in 1851,

when a catalogue was first published, 3,000 volumes and 1,500 tracts. Fifteen years later, a second edition was issued, and the numbers then were 5,500 volumes and 3,200 tracts. In 1873 it was ascertained by actual enumeration that the number of volumes was 10,443, including 320 volumes of tracts, and at the present time it consists of about 21,000 volumes, occupying 2,238 lineal feet of shelves. It may be said to include most English works, and a great many foreign ones, on Engineering or allied subjects, together with an ample provision of standard scientific works. Indeed it has been the aim of the management to take care that any treatise an engineer may reasonably want for his professional work, shall be found in the Institution. There is a MS. Catalogue of the Library, in three thick folio volumes devoted to Authors, and one volume to subjects.

Trust Funds and Premiums.

The Trust Funds under the charge of the Institution include the bequest of Thomas Telford, the donation of Charles Manby, and the bequests of Joseph Miller and of Thomas Howard.

The Telford Fund was left "in trust, the interest to be expended in annual premiums under the direction of the Council." The sum bequeathed was £2,000, and this was invested, in 1835, in £1,945 19*s*. Three Per Cent. Consols. On the division of the residuary estate of Telford further sums were received, namely: in 1850, £605 16*s*. 10*d*. Consols, and £2,342 17*s*. 1*d*. Reduced; in 1867, £287 15*s*. Consols, and £227 8*s*. Reduced; and, in 1874, a final apportionment of £15 15*s*. 10*d*. Reduced. These sums, with the original investment, amounting together to £2,839 10*s*. 10*d*. Consols, and £2,586 0*s*. 11*d*. Reduced, were transferred, in 1883, into one Stock, namely:—£5,425 11*s*. 9*d*. Consols, representing the Bequest. In 1862 a sum of £1,669 8*s*. 6*d*.—being the balance of Unexpended dividends from 1835 to that date—was invested in £1,775 19*s*. 8*d*. Consols. This, and further similar sums invested from time to time up to the year 1879, increased the Stocks to £2,377 10*s*. 5*d*. Consols, and £913 2*s*. 7*d*. Reduced, which were transferred, in 1883, into one Stock, namely:—£3,290 13*s*. Reduced, representing the Unexpended dividends. The annual income from these combined sources is about £250.

The Manby Donation, given "to form a Fund for an annual premium or premiums for Papers read at the Meetings," is invested in £250 Great Eastern Railway Four Per Cent. Debenture Stock.

The Miller Fund originated in a bequest of £3,000, received in

1860, "for the purpose of forming a Fund (which I desire may be called the 'Miller Fund'), for providing premiums or prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" In the following year this was invested in £2,000 Lancashire and Yorkshire Railway and £1,100 Norfolk (Great Eastern) Railway Four Per Cent. Debenture Stocks, which were transferred, in 1879, to Institution-account in exchange for £3,125 New Three Per Cents., which had been purchased at a cost of £3,000. The Unexpended dividends which accumulated in the years preceding the establishment of the Student class were invested in £643 19*s.* 8*d.* Consols, and £1,355 14*s.* 11*d.* Reduced, now, by a transfer effected in 1883, represented by one security, namely, £1,999 14*s.* 7*d.* Three Per Cent. Reduced. The income of these two investments is nearly £150 per annum.

The Howard Bequest, received at the end of 1872, consisted of a sum of £500 free of legacy duty, which was invested in £551 14*s.* 6*d.* New Three Per Cents. The interest on this sum was directed "to be applied in such manner and under such conditions and restrictions as the Council of the said Institution may think most expedient, for the purpose of presenting periodically a Prize or Medal to the Author of a treatise on any of the Uses or Properties of Iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." It was arranged to award this Prize every five years, commencing from 1877. The recipients have been Sir Henry Bessemer, F.R.S., and the late Sir William Siemens. The next award will be made in 1887.

The nominal capital of these several Trust Funds (inclusive of Unexpended dividends) is £14,642 13*s.* 10*d.*, which in the year ending the 31st of March, 1886, produced an income of £427 11*s.* 9*d.*

In 1884, the Council accepted a bequest (subject to a life interest) from the widow of Henry Robinson Palmer, Vice-President, of the income of £1,381 1*s.* 6*d.* Three Per Cent. Metropolitan Consolidated Stock. This is to be devoted to the foundation of a scholarship at the University of Cambridge, to be called the Palmer Scholarship, tenable only by the son of a Civil Engineer in need of help. The Council is to have the nomination to the scholarship.

The Annual Dinner.

At the Annual Meeting held on the 21st of January, 1823, it was resolved to commemorate the establishment of the Institution by the members and their friends dining together. The dinner

took place on the 7th of the following month at the London Coffee House, Ludgate Hill; and it was continued annually till 1827, after which it seems to have fallen into abeyance. In 1862 the Council revived the practice, and it has been continued without intermission to the present time. This year the dinner was held on the 27th of March in the Hall of the Society of Lincoln's Inn, by the very kind permission of the Treasurer and Benchers, and was attended by their Royal Highnesses the Prince of Wales, Prince Albert Victor, and the Duke of Cambridge, by other distinguished guests, and by many of the leading members of the profession.

PROCEEDINGS OF THE SESSION, 1885-86.

Referring now more particularly to the proceedings of the past Session, it may be stated that in the twelve months ending the 31st of March last, the changes[1] that occurred in the Roll of the

[1] These changes are shown in detail in the following Table:—

—	Dec. 1, 1884, to Mar. 31, 1885.					April 1, 1885, to March 31, 1886.				
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Totals.
Numbers at commencement	20	1,416	1,844	502	3,782	20	1,485	1,932	507	3,944
Transferred to Members	..	..	37	2		..	..	40	..	
Do. to Associate Members	..	..	..	..		..	..	..	2	
Elections	..	33	132	11	179	2	52	263	21	342
Restored to Register	..	1	2	..		..	1	2	1	
Deaths	..	3	5	3		2	24	19	8	
Resignations	..	1	4	1	−17	..	11	14	13	−112
Erased	..	..	..	..	162	..	1	15	5	230
Numbers at termination	20	1,485	1,932	507	3,944	20	1,542	2,111	501	4,174

The Deceases have been:—

Honorary Members:—Viscount Halifax, G.C.B.; and Henri Tresca.

Members:—Frederick Morris Avern; Peter William Barlow, F.R.S.; Frederick Barry; Peter Duckworth Bennett; James Bolland; William Bayley Bray; Robert Davison; Robert Handcock; George Willoughby Hemans; Ailsa Janson;

Institution included the elections of 52 Members, 263 Associate Members, 2 Honorary Members, and 21 Associates; and the restoration to the register of 1 Member, 2 Associate Members, and 1 Associate, together 342; while the losses by deaths, resignations and erasures have been 112, leaving a net increase of 230, or at the rate of nearly 6 per cent.

In the same period 230 Candidates were admitted as Students, and 147 Students were withdrawn from the list, showing an increase of 83, and bringing up the total number to 926.

Twenty-five Ordinary Meetings have been held in the present Session, and eighteen Papers, treating of twelve different subjects, have been read and discussed. These related to the "Steam-Engine Indicator," "High-Speed Motors" and "Dynamo-Electric Machines," "Construction in Earthquake Countries," "Gas-Producers," "The Injurious Effect of a Blue Heat on Steel and Iron," "The River Seine," "The Explosion of Gaseous Mixtures in a

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Professor Henry Charles Fleeming Jenkin, F.R.SS. L. & E.; James Kitson; John Towlerton Leather; Joseph Leece; Francis Mathew; Edward Newcombe; George Gordon Page; William Rhodes; Joshua Richardson; Joseph d'Aguilar Samuda; David Scott; Thomas Macdougall Smith; Frederick Swanwick; and George Wilson (*Sheffield*).

Associate Members:—Alan Charles Bagot; Nathaniel St. Bernard Beardmore; John George Blackett; Herbert Chapman; Bernard Culbard; John Henry Eykyn; Charles Cockburn Gibbons; William Jackson; Frank James; Thomas Nesham Kirkham, Jun.; Alexander Anderson Kyd; Samuel Robert Linging; David Manuel; Samuel Pontifex; Arthur Sulivan; Benjamin Warnes Thurston; Albert Harrison Turner; James Henry Waller; and John Robson Warham.

Associates:—*Major* Ambrose Awdrey, R.E.; Thomas Bagnall; Edwin Crosley; Charles Frewer; Frederick William Hartley; *Lt.-Col.* Patrick Montgomerie, R.E.; Alexander Ogilvie; and Michael Patterson.

The Resignations were:—

Members:—Charles William Archibald; Walter Marr Brydone; William Bellingham Carter; William Langton Coke; Jackson Golding; Henry Gooch; Charles Buchanan Ker; Francis Charles Liddell; William Neill; Robert Tyndall; and Clifford Wigram.

Associate Members:—William Borrer, Jun.; Francis Eustace Burke; George Ralph Fitz-Roy Cole; William Young Craig; Godfrey Darbishire; Charles William Dempsey; Sidengham Duer, B.Sc.; Telford Field; Charles James; William John Adamson Parker; Robert Ormiston Paterson; Arthur John Peele; Walter Thomas Shute; and Charles Henry Alexander Twidale.

Associates:—William Atchison; William Darnbrough Cameron; *Lt.-Gen.* Anthony Charles Cooke, C.B., R.E.; Fung Yee; Sydney Gedge, M.A.; *Maj.-Gen.* Edward Charles Acheson Gordon, R.E.; Samuel Hunter; Henry Augustin Ornano Mackenzie; John Marshman; Charles Marshall Poole; *Maj.-Gen. Sir* Peter Henry Scratchley, K.C.M.G., R.E.; Joseph Smith; and Walter Williams.

Closed Vessel," "Railways in Newly-Developed and in Mountainous Countries," "Water Purification," "Brickmaking by Machinery," "The Mersey Railway," "The Mersey Railway Lifts," and "Modern Machine Tools."

For some of the above communications, the Council has had the satisfaction to award, out of the Trust Funds appropriated for the purpose, Medals and Premiums as under:—a Telford Medal and a Telford Premium to Gisbert Kapp, Assoc. M. Inst. C.E.; a Telford Medal and a Telford Premium to Charles Edmund Stromeyer, Assoc. M. Inst. C.E.; a Watt Medal and a Telford Premium to John Imray, M.A., M. Inst. C.E.; a Telford Medal and a Telford Premium to Leveson Francis Vernon-Harcourt, M.A., M. Inst. C.E.; a Telford Premium to Dugald Clerk; a George Stephenson Medal and a Telford Premium to Francis Fox (of Westminster), M. Inst. C.E.; a Watt Medal and a Telford Premium to William Wilson Hulse, M. Inst. C.E.; Telford Premiums to William Edmund Rich, M. Inst. C.E.; Henry Ward, Assoc. M. Inst. C.E.; and Professor Osborne Reynolds, M.A., F.R.S., M. Inst. C.E.; and the Manby Premium to Arthur William Brightmore, B.Sc., Stud. Inst. C.E.

For Papers printed in the second section of the Proceedings without being publicly discussed the following awards have been made:—a George Stephenson Medal and a Telford Premium to Stanislao Fadda; and Telford Premiums to James Strachan, M. Inst. C.E.; Robert Hunter Rhind, M. Inst. C.E.; Thomas Andrews, F.R.S.E., Assoc. M. Inst. C.E.; Bryan Donkin, Jun., M. Inst. C.E.; Frank Salter, B.Sc., Assoc. M. Inst. C.E.; and to John George Mair, M. Inst. C.E.

During the past session thirteen Papers were read at twelve Students' Meetings, the subjects having been fairly representative of the varied character and the advanced position of engineering of the present day. The attendance of Students at their special meetings on Friday evenings has been very good.

Miller Prizes have been awarded to the Authors of several of the Papers read at the Supplemental Meetings of Students, namely, John Goodman, Wh. Sc., Henry Albert Cutler, Leslie Stephen Robinson, and Edward Carstensen de Segundo, William Andrew Legg, Gilbert Macintyre Hunter, Llewelyn Birchall Atkinson, Rudolph Emil von Lengerke, David Sing Capper, M.A., Maurice FitzMaurice, and Ernest William Moir.

A series of nine visits to engineering works of magnitude was organized in the spring, and the Council wishes to put on record its appreciation of the kindness which prompted the heads of these

establishments to afford facilities to the Students for becoming acquainted with some of the important practical works of the profession.

Income and Expenditure.

Briefly stated, the accounts for the Session 1885-86, as appended to this Report, show that the receipts from all sources amounted to £19,945 15*s.* 9*d.*, against payments, (including an investment on capital account,) aggregating £19,113 17*s.* 1*d.*, so that the balances on deposit, and in the hands of the Treasurer and of the Secretary, are £831 18*s.* 8*d.* in excess of what they were on the 31st of March, 1885. These balances now aggregate £4,067 17*s.* 5*d.*, and it is estimated that this amount and the major part of sums still to be received, will be required to meet the expenditure during the remaining nine months of the current year.

The gross receipts and payments are presented under three heads on each side of the financial statement, and may be tabulated as under:—

Receipts.	£.	s.	d.	Payments.	£.	s.	d.	Excess of Receipts over Payments. £.	s.	d.
Income . .	15,691	8	6	General . .	15,487	0	1	204	8	5
Capital . .	3,813	12	0	Investment .	3,281	5	0	532	7	0
Trust Funds .	440	15	3	Trust Funds.	345	12	0	95	3	3
Totals .	£19,945	15	9		£19,113	17	1	£831	18	8

Of the income, £2,041 5*s.* 2*d.* arose from dividends on capital investments; the capital receipts include Admission Fees and Life Compositions; and the dividends on Trust Funds comprised those produced by the Telford, the Manby, the Miller, and the Howard Bequests. As regards the general expenditure, three-fifths nearly (or £9,178 4*s.* 11*d.* actually), will be found debited to publications, representing the cost of four and a half volumes of Minutes of Proceedings, of two of the series of lectures, namely, those on Heat and on Hydro-Mechanics, and of new copies of the Charter, with By-Laws and lists of Members. The entire cost of the first volume of the Proceedings for the Session 1885-86 is included in the above amount, having been paid for in the first quarter of 1886, and it is intended that the remaining three volumes shall be defrayed out of the current year's receipts, so

that the income of any particular year, mainly arising from Annual Subscriptions, shall bear the cost of the publications of that year, as it has done for some time, but which it did not precisely do in the twelve months under review.

On the 20th of October last a demand was made by the Inland Revenue Department for a return of the property of the Institution liable to assessment under "The Customs and Inland Revenue Act, 1885." This demand was referred to the Solicitors, who took the opinions of the most eminent Counsel, by whom the Council was advised that the Institution is entitled to claim exemption for the whole of its property under Section XI., sub-section 3 of the Act, on the ground that it is all legally appropriated and applied for the promotion of education and of science. A return was accordingly made to the Inland Revenue Department to the above effect. After some further correspondence, the Department on the 19th of April last, notified that, in accordance with Section XVIII., sub-section 1 of the Act, they had assessed the Institution in the sum of £80 19*s.* 11*d.* Against this assessment notice of appeal has been lodged.

The present year is, in a certain sense, the Jubilee Year of the Institution, and a reference to the Historical and Descriptive Notice now given will show that the members have good reason to be proud of the progress it has made in the half-century, and may be well satisfied with its present position.

[RECEIPTS AND EXPENDITURE.

N 2

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance, Mar. 31, 1885, viz. :—						
On Deposit at Bankers	2,000	0	0			
Cash in the hands of the Treasurer	935	6	5			
" " Secretary	300	12	4			
				3,235	18	9

Income.

	£.	s.	d.	£.	s.	d.
— Subscriptions:—						
Arrears	375	18	0			
Current	12,690	0	6			
Advance	129	19	6			
				13,195	18	0
— Library-Fund				205	4	6
— Minutes of Proceedings:—Repayment for Binding, &c.				231	8	2
— Publication Fund				3	3	0
— Interest on Deposit Account				13	17	2
— Miscellaneous Receipts				0	12	6

— Dividends: 1 year on

£.	*Institution Investments.*	£.	s.	d.	£.	s.	d.	£.	s.	d.
6,000	New Three per Cents.	174	8	6						
3,000	Metropolitan Board of Works 3½% Stock	101	12	3						
3,000	Caledonian Railway 4% Debenture Stock	116	1	9						
6,000	Great Eastern Ditto	232	10	0						
3,000	Great Northern Ditto	116	5	0						
6,000	Great Western Ditto	232	10	0						
3,000	Highland Ditto	116	1	9						
6,000	Lancs. and Yorks. Ditto	232	10	0						
1,500	L. B. & S. C. Ditto	58	2	6						
6,000	L. & N. W. Ditto	232	10	0						
3,000	Midland Ditto	116	5	0						
3,000	North Eastern Ditto	116	5	0						
1,500	L. B. & S. C. 4½% Ditto	65	7	10						
3,000	Man. Shef. & L. Ditto	130	15	7						
	New Purchase.									
3,000	Metropolitan Board of Works 3½% Stock	0	0	0						
£57,000	Total nominal or par value.				2,041	5	2			
								15,691	8	6
	Carried forward							£18,927	7	3

from the 1ST APRIL, 1885, *to the* 31ST MARCH, 1886.

EXPENDITURE.

Cr.

GENERAL EXPENDITURE.

	£.	s.	d.	£.	s.	d.
By House and Establishment Charges:—						
Repairs, General	293	7	3			
Rent	637	3	7			
Rates and Taxes	418	3	4			
Insurance	45	11	6			
Rent of Telephone	23	13	0			
Fixtures and Furniture	3	15	0			
Lighting and Warming	133	14	9			
Refreshment at Meetings	70	16	10			
Assistance at Meetings	35	14	0			
,, Students' Meetings	19	11	0			
Household Expenses	170	0	10			
				1,851	11	1
— Postages, Telegrams, and Parcels	216	12	3			
— Stationery and Printing	600	2	1			
— Watt Medal	2	7	6			
— George Stephenson Medal	2	7	6			
— Diplomas	55	10	1			
— Annual Dinner (Official Invitations, &c.)	277	19	2			
				1,154	18	7
— Salaries	1,900	0	0			
— Clerks, Messengers, and Housekeeper	751	18	4			
— Donation to late Housekeeper	30	0	0			
				2,681	18	4
— Library:—						
Books	167	7	5			
Periodicals	100	3	4			
Binding	170	15	7			
Checking and Revising Catalogue	90	0	0			
				528	6	4
— Publications:—						
"Minutes of Proceedings," Vols. lxxix. (balance), lxxx., lxxxi., lxxxii. and lxxiii.	7,513	9	6			
Lectures on "Heat"	644	9	7			
Lectures on "Hydro-Mechanics"	721	18	8			
Charter, By-Laws, and Lists of Members	257	7	2			
Manby Portrait	41	0	0			
				9,178	4	11
— Legal Expenses				92	0	10
Carried forward				£15,487	0	1

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.

						£.	s.	d.	£.	s.	d.
			Brought forward						18,927	7	3
			Capital.								
			To Admission-Fees			3,446	2	0			
			— Life-Compositions			367	10	0	3,813	12	0
			Trust-Funds.								
			Telford Fund.	£.	s.	d.					
			— Balance of Telford Premium	13	3	6					
			— Dividends :—								
£.	s.	d.									
5,425	11	9	Three % Consols	157	6	10					
3,290	13	0	Three % Reduced (Unexpended Dividends)	95	11	11					
8,716	4	9	Total nominal or par value.				266	2	3		
			Manby Donation.								
250	0	0	Great Eastern Ry. Four % Debenture Stock				9	13	9		
			Miller Fund.								
3,125	0	0	New Three per Cents.	90	16	2					
1,999	14	7	Three % Reduced (Unexpended Dividends)	58	3	2					
5,124	14	7	Total nominal or par value.				148	19	4		
			Howard Bequest.								
551	14	6	New Three per Cents.				15	19	11	440	15	3
										£23,181	14	6

Summary of Investments.

	£.	s.	d.	£.	s.	d.
Institution-Investments				57,000	0	0
Trust-Funds—						
Telford Fund	8,716	4	9			
Manby Donation	250	0	0			
Miller Fund	5,124	14	7			
Howard Bequest	551	14	6	14,642	13	10
				£71,642	13	10

from the 1ST APRIL, 1885, *to the* 31ST MARCH, 1886.

EXPENDITURE—*continued.*

Cr.

				£.	s.	d.
	Brought forward			15,487	0	1

CAPITAL-INVESTMENTS.

				£.	s.	d.
By £3,000	Metropolitan Board of Works $3\frac{1}{2}$ % Stock			3,281	5	0

TRUST-FUNDS.

	£. s. d.	£. s. d.	£. s. d.
By Telford Premiums	196 14 1		
— Telford Medals	6 0 0		
		202 14 1	
— Miller Scholarship	40 0 0		
— Miller Prizes	102 17 11		
		142 17 11	
			345 12 0
			19,113 17 1
— Balance, March 31st, 1886, viz.:—			
On Deposit at Bankers		3,000 0 0	
Cash in the hands of the Treasurer . . .		1,058 17 0	
„ „ Secretary . . .		9 0 5	
			4,067 17 5
			£23,181 14 6

Examined with the Books and found correct.

(Signed) H. BAUERMAN, H. G. HARRIS, } *Auditors.*

JAMES FORREST, *Secretary.*
5th May, 1886.

PREMIUMS AWARDED.

Session 1885–86.

The Council of The Institution of Civil Engineers have awarded the following Premiums:

For Papers Read and discussed at the Ordinary Meetings.

1. A Telford Medal and a Telford Premium to Gisbert Kapp, Assoc. M. Inst. C.E., for his Paper on "Modern Continuous-Current Dynamo-Electric Machines and their Engines."
2. A Telford Medal and a Telford Premium, to Charles Edmund Stromeyer, Assoc. M. Inst. C.E., for his Paper on "The Injurious Effect of a Blue Heat on Steel and Iron."
3. A Watt Medal and a Telford Premium to John Imray, M.A., M. Inst. C.E., for his Paper on "High-Speed Motors."
4. A Telford Medal and a Telford Premium to Leveson Francis Vernon-Harcourt,[1] M.A., M. Inst. C.E., for his Paper on "The River Seine."
5. A Telford Premium to Dugald Clerk,[2] for his Paper "On the Explosion of Homogeneous Gaseous Mixtures."
6. A George Stephenson Medal and a Telford Premium to Francis Fox (of Westminster), M. Inst. C.E., for his Paper on "The Mersey Railway."
7. A Watt Medal and a Telford Premium to William Wilson Hulse, M. Inst. C.E., for his Paper on "Modern Machine-tools and Workshop-appliances, for the treatment of Heavy Forgings and Castings."
8. A Telford Premium to William Edmund Rich, M. Inst. C.E., for his Paper on "The Hydraulic Passenger-Lifts at the Underground Stations of the Mersey Railway."
9. A Telford Premium to Henry Ward, Assoc. M. Inst. C.E., for his Paper on "Brickmaking."
10. A Telford Premium to Professor Osborne Reynolds, M.A., F.R.S., M. Inst. C.E., for his Paper "On the Theory of the Indicator, and the Errors in Indicator-Diagrams."

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[1] Has previously received a Telford Premium and a Manby Premium.
[2] Has previously received a Watt Medal and a Telford Premium.

11. The Manby Premium to Arthur William Brightmore, B.Sc., Stud. Inst. C.E., for his Paper "Experiments on the Steam-Engine Indicator."

For Papers Printed in the Proceedings without Being Discussed.

1. A George Stephenson Medal and a Telford Premium to Stanislao Fadda, for his Paper on "The Design and Construction of Railway Rolling-stock in Italy."
2. A Telford Premium to James Strachan, M. Inst. C.E., for his Paper on "The Karachi Waterworks."
3. A Telford Premium to Robert Hunter Rhind, M. Inst. C.E., for his Paper "Coefficients of Discharge applicable to certain Submerged Weirs of large Dimensions."
4. A Telford Premium to Thomas Andrews, F.R.S.E.,[1] Assoc. M. Inst. C.E., for his Paper "Effect of Temperature on the Strength of Railway-Axles."
5. A Telford Premium to Bryan Donkin, jun., M. Inst. C.E., and a Telford Premium to Frank Salter,[2] B.Sc., Assoc. M. Inst. C.E., for their joint Paper "Experiments on the Measurement of Water over Weirs."
6. A Telford Premium to John George Mair,[3] M. Inst. C.E., for his Paper "Experiments on the discharge of Water of different Temperatures."

For Papers Read at the Supplemental Meetings of Students.

1. A Miller Prize to John Goodman, Wh. Sc., Stud. Inst. C.E., for his Paper on "Recent Researches in Friction."
2. A Miller Prize to Henry Albert Cutler, Stud. Inst. C.E., for his Paper "The Stability of Voussoir Arches."
3. A Miller Prize to Leslie Stephen Robinson, Stud. Inst. C.E., and a Miller Prize to Edward Carstensen de Segundo, Stud. Inst. C.E., for their joint Paper "Experiments on the Relative Strength of Cast-iron Beams."
4. A Miller Prize to William Andrew Legg, Stud. Inst. C.E., for his Paper on "The Construction of the Hirnant Tunnel on the Line of Aqueduct of the Vyrnwy Waterworks for the supply of Liverpool."

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[1] Has previously received a Telford Medal and a Telford Premium.
[2] Has previously received a Miller Prize.
[3] Has previously received a Watt Medal and a Telford Premium.

5. A Miller Prize to Gilbert Macintyre Hunter, Stud. Inst. C.E., for his Paper on "Locomotive Engine- and Carriage-Sheds, as used on the Caledonian Railway."
6. A Miller Prize to Llewelyn Birchall Atkinson, Stud. Inst. C.E., for his Paper on "Electrical-measuring Instruments."
7. A Miller Prize to Rudolph Emil von Lengerke, Stud. Inst. C.E., for his Paper on "A Graphic Method of Determining the Flow of Water in Pipes."
8. A Miller Prize to David Sing Capper, M.A., Stud. Inst. C.E., for his Paper on "Continuous Railway-Brakes."
9. A Miller Prize to Maurice FitzMaurice, Stud. Inst. C.E., for his Paper on "The Foundations of the Forth Bridge."
10. A Miller Prize to Ernest William Moir, Stud. Inst. C.E., for his Paper on "The Building, Launching and Sinking of the Queensferry Pneumatic Caissons at the Forth Bridge."

SUBJECTS FOR PAPERS.

Session 1886–87.

The Council of The Institution of Civil Engineers invite Original Communications on any of the Subjects included in the following list, as well as on other questions of professional interest. For approved Papers the Council have power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The Telford Fund, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces £260 annually.

2. The Manby Donation, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises £150 per annum. Out of this Fund the Council have established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and are prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to nearly £16. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1887.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made (except in the cases of the Miller and the Howard bequests, which are limited by the donors) between essays from any person, whether belonging to the Institution or not, or whether a Native or a Foreigner.

List.

1. The Principle of Work applied to the Calculation of the Strength of Structures.
2. The Construction and Testing of Air-locks and Shaft-tubes for Sinking Foundations.
3. Concrete-work under water.
4. The Physical Properties of Materials under Stress.
5. The Thermic Properties of Metals commonly used in the Arts, especially with respect to Conductivity and Diathermancy at high temperatures.
6. The manufacture, properties, and use of Castings of Malleable Cast-Iron and Cast-Steel.
7. The Present Position of the Manufacture of Steel—its defects, and suggestions for its improvement.
8. The various Processes of Tempering Steel, and their effects.
9. Methods of Compressing Steel while in a Fluid state.
10. On Forging by Hydraulic Pressure.
11. The Independent Testing of different types of Steam-Engines, including Triple-Expansion and Quadruple-Expansion Engines.
12. The Production of Heating-Gas from Coal.
13. Compressed Oil Gas, and its applications.
14. Modern Appliances for the Consumption of Liquid Fuel for Steam-Boilers and other Industrial Uses.
15. The Application of Steel for Sleepers, and the best means of attaching the rails to them.
16. The Application of the Compound Principle to Locomotive and Portable Engines.
17. The Driving-axles of Locomotive Engines.

18. The Design of Rolling Stock for the more Economical Conveyance of Goods on Railways.
19. Steering and other Small Engines for use on board ship.
20. The Machinery of Modern War Ships.
21. Machine-Guns.
22. On Built-up Crank-Shafts for Marine Engines, and on the liability of crank- and screw-shafts to fracture.
23. The Structural and other Defects to which Iron and Steel Ships are subject, and their Causes.
24. Tools used in the Building of Iron and Steel Ships.
25. Recent Investigations on the Tides.
26. Dredging-Operations and Appliances.
27. The Construction of Hydraulic Cranes for Docks, with special reference to economy of Quay Space.
28. Uniformity in system (international) of Coast-Lighting by lighthouses, light-vessels, and their auxiliaries, automatic lighted beacons and buoys.
29. The relative advantages of High Masonry Dams compared with Earthen Banks for impounding Water.
30. Water-Supply from the Chalk and other geological formations.
31. Water Meters and the Sale of Water by Measure.
32. Machinery and Arrangements for Distilling Water by multiple effect.
33. Filter-Presses for separating Solids from Fluids, particularly for the treatment of Sewage-Sludge, and ultimate Sewage-Treatment and Disposal.
34. Accidents in Mines; their Causes, Warnings, and Prevention.
35. Winding-Machinery and Balancing-Apparatus for Mines, and the cost per ton of winding under different conditions and varying depths.
36. Underground Haulage, especially on the application of compressed air and of electrical power.
37. The Mining of Rock Salt and Brine-pumping, including the manufacture of common salt.
38. Gold-Quartz crushing and amalgamating-appliances.
39. The Manufacture and Desilverization of Lead.
40. Appliances for the rapid Shipment of Coals, with a comparison of different methods.

41. Electro-Motors; their theory, practical construction, efficiency, and power.
42. The Construction and Maintenance of Secondary Batteries.
43. The Distribution of Electric Currents for the Electric Lighting of Towns.
44. Thermo-Electric Batteries, and their Application to Electro-plating and other purposes.
45. The Application of Dynamo-Electric Machines to the Electro-deposition of Metals from their ores.

Instructions for Preparing Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1500 words in length.

Illustrations, when necessary, should be drawn on tracing-paper, to as small a scale as is consistent with distinctness, and ready to be engraved. When an illustrated communication is accepted for reading, a series of Diagrams will be required sufficiently large and boldly coloured to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, cannot be read at a Meeting of the Institution, nor be admitted in competition for the Premiums.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it is dealt with in the succeeding one.

William Pole, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street, Westminster, S.W.*
August, 1886.

Excerpt By-Laws, Section XV., Clause 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Notice.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution as a body must not be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN APRIL 1, 1885, AND MARCH 31, 1886.

AUTHORS.

Addison, P. L. No. 2,120.—Economy in Iron-Ore Mining in Cumberland. With 1 Sheet of Illustrations.

———. No. 2,130.—Methods employed in securing large and irregular-shaped Mineral Workings. With Illustrations.

Anderson, W. (Erith). No. 2,077.—On the Purification of Water by means of Iron on the large scale. (Vol. lxxxi., p. 279.)

Andrews, T. No. 2,076.—Corrosion of Metals during long exposure in Sea-water. With 4 Drawings. (Vol. lxxxii., p. 281.)

———. No. 2,123.—Effect of Temperature on the Strength of Railway Axles.

Appleby, C. J. No. 2,141.—On Cranes for Goods-Traffic, and other purposes.

Aspinall, J. A. F. No. 2,138.—Friction of Locomotive Slide-valves. With 4 Sheets of Illustrations.

Bagshaw, W. No. 2,135.—Friction Clutches.—With 10 Sheets of Illustrations.

Bauerman, H. No. 2,132.—The Salt-Industry of Stassfurt. (Vol. lxxxiii., p. 415.)

Beckingsale, E. W. No. 2,153.—Greenock Electric-Lighting.

Birch, R. W. P. No. 2,078.—The Effect of the Drought of 1884 upon the Pollution of the River Thames below London. With Appendix and 1 Drawing. (Vol. lxxxi., p. 295.)

Boulnois, H. P. No. 2,168.—Footpaths.

Brady, A. B. No. 2,129.—The Design and Construction of Locomotive-Engine Sheds. With 5 Sheets of Drawings.

———. No. 2,166.—Graphic Statics, and its practical application to the Design of Iron Girders. With 4 Sheets of Drawings.

Bruce, A. F. No. 2,084.—Spanish Tidal Flour-Mills. With 1 tracing. (Vol. lxxxi., p. 315.)

Chadwick, G. B. No. 2,102.—On the Progress of Light-Railway Construction in the Province of São Pedro do Rio Grande do Sul, Brazil. With a large Map.

AUTHORS.

Fox, W. No. 2,106.—Particulars of Borings in the Chalk at Bushey, Herts, and quantity of water obtained therefrom. With 2 Drawings.

Fowler, J. No. 2,159.—Statement of the Works carried out for the Improvement of the Navigation of the River Tees during the last Thirty Years. With 6 Drawings.

Frankland, P. F. No. 2,150.—Water-Purification; its Biological and Chemical Basis. (Vol. lxxxv., p. 197.)

Gordon, R. No. 2,104.—On the Economical Construction and Operation of Railways in Countries where small returns are expected, as exemplified by American practice. With 3 Plates and 8 Cuts. (Vol. lxxxv., p. 54.)

Gower, C. F. No. 2,145.—On the Horizontal Range of Tidal Rivers with reference to Sewage Discharge. With 1 Sheet of Drawings. (Vol. lxxxvi., *post.*)

Grover, J. W. No. 2,118.—Chalk Springs in the London Basin, illustrated by the Newbury, Wokingham, and Leatherhead Waterworks. With 13 Sheets of Illustrations.

Guérard, A. No. 2,088.—Mouth of the River Rhone. (Vol. lxxxii., p. 305.)

Harvey, R. No. 2,086.—Machinery for the Manufacture of Nitrate of Soda in the Ramirez Nitrate Factory, Northern Chili. With 4 Sheets of Drawings. (Vol. lxxxii., p. 337.)

Haswell, C. H. No. 2,090.—On Built Crank-shafts for Marine Engines, and on the Liability of Crank- and Screw-Shafts to Fracture.

———. No. 2,156.—On the Deposit of Silt, etc., in the Harbour and Bay of New York, and its effect on the Bar at Sandy Hook.

Hawgood, H. No. 2,091.—Removal of Shoals by Propeller-Sluicing, on the Columbia River, Oregon, U.S. With 1 Drawing. (Vol. lxxxiii., p. 386.)

Hetherington, J. No. 2,146.—On Utilizing Waste Air in Filter Pressing; with some results of pressing Sewage-Sludge at Chiswick.

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Hutton, R. J. . .	2	2	0
Keating, H. . . .	1	7	6
Langmuir, J. . .	1	1	0
Lapage, R. H. . .	2	2	0
Le Lievre, C. . .	1	1	0
Lomax, W. J. . .	1	1	0
McCurrick, J. M. .	2	2	0
McEwen, T. S. . .	3	3	0
Man, C. D. . . .	2	2	0
Mappin, F. T. . .	5	5	0
Masterman, C. E. .	1	1	0
May, C. R. . . .	5	0	0
Metcalfe, Sir C. H. T.	2	2	0
Moore, E. J. . . .	7	7	0
Morris, E. L. . . .	1	1	0
Napier, J. M. . . .	6	0	0
Nettlefold, H. . .	3	3	0
Newton, W. G. . .	2	2	0
Ollis, W. B. . . .	2	2	0
Ogilvie, G. T. . .	2	0	0
Ormerod, R. O. . .	1	1	0
Ough, H.	1	1	0
Palliser, H. G. . .	3	3	0
Palmer, C. S. R. . .	1	10	0
Perkins, H. F. . .	1	1	0
Radford, W. H. . .	1	1	0
Rankin, G. . . .	1	1	0
Ravenhill, T. . . .	2	2	0
Ritson, T. N. . . .	1	1	0
Sartoris, L. . . .	5	0	0
Scott, W. Hewlett .	1	1	0
Scriven, C. W. . .	1	1	0
Shuttleworth, F. H. .	1	1	0
Carried forward	164	8	0

	£.	s.	d.
Brought forward	164	8	0
Simmons, J.	1	1	0
Simpson, J. T.	2	4	0
Smedley, G. B.	1	1	0
Souza, A. P. C. de	1	7	6
Spencer, F. W.	2	12	6
Spooner, H. J.	1	1	0
Taylor, Chas..	5	5	0
Thomas, P. A.	2	2	0
Thursby, C. R.	5	0	0
Carried forward	186	2	0

	£.	s.	d.
Brought forward	186	2	0
Turner, J. H..	1	1	0
Vacher, H. P.	2	2	0
Wallis, B. G.	1	0	0
Watkeys, G.	2	2	0
Whieldon, J. H.	1	1	0
Wolfe, J. E.	3	3	0
Worthington, E.	1	1	0
Wright, J. W.	3	3	0
Young, B. H.	4	9	6
Total	£205	4	6

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Anales de la Sociedad científica argentina. *Buenos Aires.*

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Allgemeine Bauzeitung. *Wien.*
Berg- und hüttenmännisches Jahrbuch. *Wien.*
Denkschriften der k. Akademie der Wissenschaften. *Wien.*
Mittheilungen aus dem Gebiete des Seewesens. *Pola.*
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Oesterreichische Zeitschrift für Berg- und Hüttenwesen. *Wien.*
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Statistische Nachrichten von den Oesterreich-Ungarischen Eisenbahnen. *Wien.*
Technische Blätter. *Prag.*
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Annales des Travaux publics de Belgique. *Bruxelles.*
Annuaire de l'Association des Ingénieurs sortis de l'École de Liége. *Liége.*
Bulletin de l'Académie royale des Sciences de Belgique. *Bruxelles.*

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Bulletin de l'Association des Ingenieurs sortis de l'École de Liége. *Liége.*
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Le Mouvement Industriel. *Bruxelles.*
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Sect. II.—OTHER SELECTED PAPERS.

(*Students' Paper, No. 208.*)

"The Stability of Voussoir Arches."[1]

By Henry Albert Cutler, Stud. Inst. C.E.

The stability of arched structures, although in many cases imperfectly considered, is fully deserving of close investigation.

In ordinary cases a practical man may use a rule-of-thumb method with some degree of approximate accuracy; but in all cases the Author would advise a thorough investigation, which will not only give an engineer confidence in his work, but will often prove a great source of economy.

The mathematical analysis of stresses would no doubt be preferred by the mathematician, as being more strictly accurate, but the graphic method, selected by the Author for this Paper, will commend itself to the practical man, not only for its simplicity and expedition of solution, but also for the readiness with which errors can be detected.

The small errors, likely to occur in measuring strains from a diagram where the angles are very acute or obtuse, will be of no practical importance if care be taken, as the factor of safety required in practice limits the application of theory to practical purposes, thus making rigid accuracy in the determination of stresses unnecessary.

To avoid ambiguity, arched structures may be divided into two classes, namely, the voussoir arch, and the rigid arch; but the Author has dealt only with the voussoir arch, in order to give that portion of the subject a more thorough investigation.

The voussoir arch (the tenacity of the mortar being disregarded) is not capable of resisting a bending moment, and may be considered as hinged at every bed-joint in the arch-ring. To investigate the stability of an arched structure by the graphic method, it is first necessary to find the correct curve of equilibrium for the

[1] This Paper was read at a meeting of the Students on the 26th of February, 1886.

dead load or weight of the structure, and then, generally, to assume the live load as acting on one-half the arch, while the remaining half is unloaded, and to construct a second curve, both of which curves should satisfy the condition hereafter mentioned.

The curve of equilibrium of an arch is its position of rest, considering the arch to be a polygon with an infinite number of sides, and jointed at all the intersections. In voussoir arches, in almost all cases, both the dead and the moving load may be considered as acting vertically; and when an arch is subjected to vertical loads only, the horizontal thrust from the load, considered as split up and acting at the joints of a hinged polygon, will be the same at each point throughout the curve.

The curve of equilibrium may be better understood by considering a cord (Figs. 1), weighted with equal weights at 1, 2, 3, &c., to be suspended between two points; then the position of rest assumed by the cord will be a curve of equilibrium, which, if inverted (Figs. 2), would also be a curve of equilibrium for an arch of the same span and loaded in the same manner.

By reference to the diagram, it will be seen that two curves have been drawn for the same loading; but by varying the deflection or rise of the curve, as the case may be, an infinite number of curves can be drawn, all of which are true curves of equilibrium.

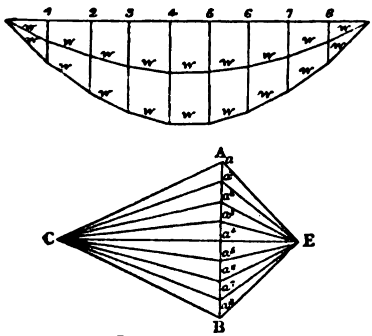
The elements of the curves in Figs. 1 and 2 are drawn by plotting on the vertical line A B, with a scale of loads the distances $a\,a^1$, $a^1\,a^2$, &c., equal to the loads acting on the cord. The loads being equal and symmetrically distributed, the reactions of each support will be equal, and therefore the apices (C and E) will be equidistant between A and B, so that the lines C D and D E, which measure the horizontal thrusts, will exactly bisect A B; therefore C D and D E are drawn equal to the horizontal thrusts which the curves are required to have, and lines joining C and E with points a, a^1, a^2, &c., will give the elements of the curves, which are produced by drawing lines w w w, &c., between 0, 1, 2, &c., parallel to the lines C a, &c.

The lines on the right and on the left of the verticals form two separate force diagrams, one for each curve; but as the weights are the same in each, they have both been drawn on the same load line.

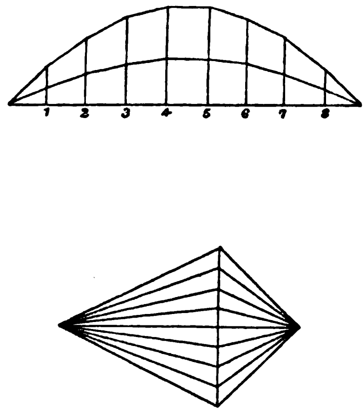
The horizontal thrust of an arch varies inversely as the rise of the arch, for the two curves, which are drawn with horizontal thrusts of 4 tons and 8 tons respectively, give rises of 5 feet and 2 feet 6 inches respectively; so that, with a constant span and

load, after having drawn one curve, the horizontal thrust of a curve with any given rise, or the rise of a curve with any given horizontal thrust, can easily be calculated. For instance, to find the rise of curve for the same span and loading as shown in Figs. 1 and 2 with a horizontal thrust of 3 tons; where R = rise

Figs. 1.



Figs. 2.



obtained, R^1 = rise required, T = horizontal thrust obtained, and T^1 = horizontal thrust required, $T^1 : T :: R : R^1$;

therefore $$R^1 = \frac{T\,R}{T^1},$$

and by substituting $R^1 = \dfrac{8 \times 2 \cdot 5}{3} = 6 \cdot 7$ feet.

To find the horizontal thrust with a rise of 6·7 feet, $R^1 : R :: T : T^1$;

therefore $$T^1 = \frac{R\,T}{R^1},$$

and by substituting, $T^1 = \dfrac{2 \cdot 5 \times 8}{6 \cdot 7} = 3$ tons.

As it is possible to draw such a variety of curves, it is a matter of considerable importance that the proper curve should be selected for the structure under consideration.

When the curve of equilibrium does not fall within the arch-ring, a bending moment is produced, tending to increase the curvature of the arch if lying inside the neutral line; and to diminish it if lying outside. In Fig. 3 the dotted lines represent the way in which the arch would fail if acted upon by a curve of pressure A A A A.

Masonry and brick, or voussoir arches not being capable of resisting a bending moment, the condition to be fulfilled is that the curve of equilibrium must practically coincide with the neutral line. Disregarding the elasticity of the material, the arch would not collapse so long as the curve was everywhere within the depth of the arch-ring, but when close to the edge, nearly all the strain is taken through a small portion of the voussoir, while the remaining portion is nearly relieved from pressure. Professor Rankine has limited the curve of equilibrium to the middle third of the arch-ring, which is a simple practical rule. In Fig. 4 the middle third is represented by the space between the dotted lines.

Fig. 3.

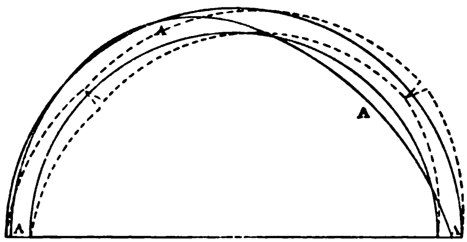
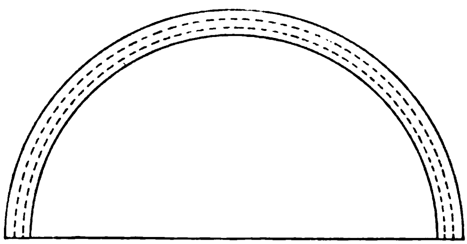


Fig. 4.

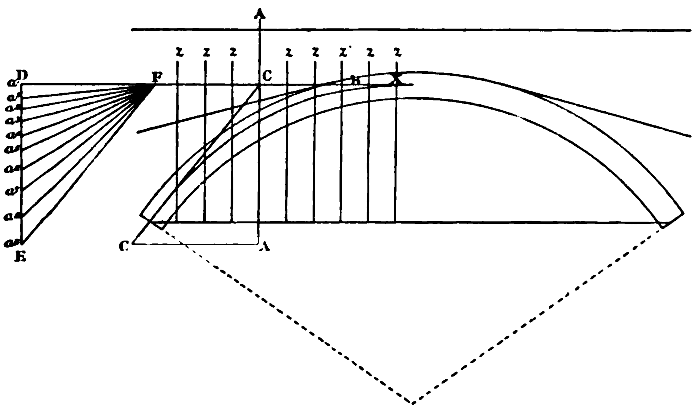


The curve of equilibrium to satisfy the above condition is found by fixing points in the curve somewhere within the middle third at the crown and springing; if the deviation of the curve from the neutral line is not within the limit at every other point, generally, either the loading, the curve of the arch, or the depth of the voussoir, must be altered until the condition is fulfilled.

To draw the curve of equilibrium, the neutral line of the arch (Fig. 5) must be divided into a convenient number of parts of equal horizontal distance; the dead load acting upon each division can then be calculated by drawing perpendicular lines up through the arch from the points of division, and proportioning the weights to the areas between the perpendicular lines.

It is not necessary that the arch should be divided into equal horizontal portions, but the calculation of weights is much facilitated thereby. The loads thus obtained may now be considered as acting at points in the centre of each division, as shown by the vertical lines *z*, *z*, *z*, and the centre of gravity of each half-arch can be found by taking moments round the abutments; that is, by multiplying each weight in the half-arch by its horizontal distance from one of the abutments, and dividing the sum of these products by the total weight of the half-arch, which will give the horizontal distance of its centre of gravity from the abutment round which moments have been taken. When an arch is symmetrically loaded on each side of the centre, it will only be necessary to deal with one half, as the two halves will be identical.

Fig. 5.



The vertical line A A must now be drawn through the centre of gravity of the load, and the line of thrust B at the crown (which may be anywhere within the middle third, and which with symmetrical loads will be horizontal) produced until it cuts the vertical A A; then the line C C, connecting this point of intersection with the springing-point, will complete the curve of equilibrium for the load, assuming that it is acting at the centre of gravity of the half-arch; the direction of the thrusts at the crown and springing thus being fixed, their magnitudes can easily be determined by plotting the weight of the half-arch on the vertical line A A from C downwards, and completing the triangle of forces C C A.

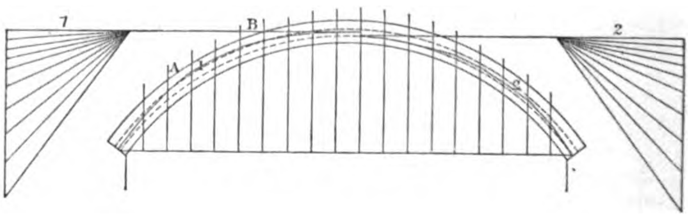
By producing the line of thrust B C to D, and drawing D E and E F parallel to C A and C C, a triangle of forces for each weight acting separately can be drawn, which will give the elements of

the curve of equilibrium, and also measure the strain in any part of the arch.

The vertical line C A being equal to the total load on the half-arch, the line D E in the force diagram being drawn equal and parallel to it, can be divided into a number of parts $a\,a^1$, $a^1\,a^2$, &c., equal to the different weights making up the total load; commencing at the top set-off $a\,a^1$, equal to the weight nearest the crown, and $a^1\,a^2$, &c., equal to the remaining weights; then lines joining the points $a^1\,a^2$, &c., with the point F will complete the force diagram.

To construct the curve of equilibrium, draw lines parallel to a^1 F, a^2 F, &c., between the lines z, z, z, commencing with a^1 F, which must be drawn from the intersection of the line of thrust at the crown with the first vertical line z, that is, at point X; and on completing the diagram, if drawn correctly, the line a^9 F will exactly coincide with the line C C. In drawing a curve of equi-

FIG. 6.



librium, it is usual to take the neutral line of the arch-ring at the crown and springing for fixed points in the curve; but when the curve thus drawn does not quite fall within the middle third, another curve may sometimes be drawn, by varying these points (within the prescribed limits) which will satisfy the required condition. An example of this will be seen in Fig. 6, which has two curves of equilibrium. No. 1, which was drawn by fixing points in the neutral line at the crown and springing, did not quite satisfy the above conditions between A and B, but by altering the fixed points in the crown and springing to the lower limit of the middle third, and drawing curve No. 2, the required result was obtained.

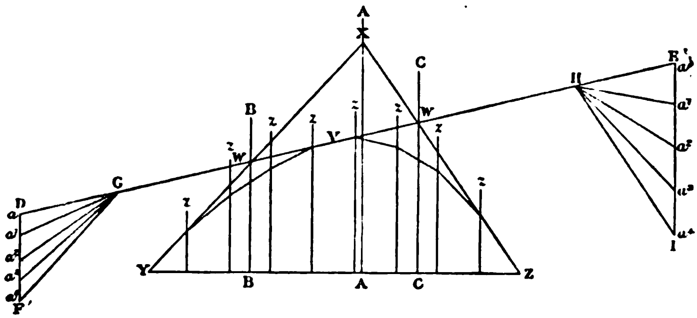
In dealing with arches which are not loaded symmetrically, the diagrams become rather more complicated, but yet are easily constructed; for example, Fig. 7 represents an arch which has a uniform dead load, together with a live load on one half the arch only. In this case it is necessary to draw diagrams for both sides,

as the curve will be different, and the line of thrust at the crown will not be horizontal, as is the case with symmetrical loads.

Suppose it be required to find the curve of equilibrium for a span of 18 feet with loads of 1 ton acting at each line of division *z, z, z, z*, from the left abutment to the crown, and loads of 2 tons on each line of division from the crown to the right abutment; then by finding the sum of the moments of all the weights round the left abutment, and dividing their sum by the sum of the weights, the distance of the centre of gravity, A A from the left abutment will be obtained; and by repeating the process for the weights in the left half of the arch round the left abutment and the right half round the right abutment, the results will be the distances of the centres of gravity B B and C C from their respective abutments.

By assuming the whole of the load to be acting at A in the

FIG. 7.



centre of gravity of the load, the curve of equilibrium would be two straight lines X Y and X Z, which must be drawn tentatively until they have been so fixed that a line connecting the points of intersection W W with lines B B and C C falls on the fixed point, at the crown of the arch through which it is intended the curve of equilibrium shall pass; then the polygon Y W W Z will be the curve of equilibrium for the load, considering it concentrated at two points B and C, and the line W W will represent the direction of the thrust at the crown.

By producing W W to D and E, and drawing D F and E I parallel to B B and C C and equal to the respective loads on each half-arch, the lines F G and H I, drawn from points F and I parallel to X Y and X Z, will complete the triangles of force D F G and E H I, and the elements of the curve will be found by dividing the verticals D F and E I into portions a, a^1, a^2, &c.,

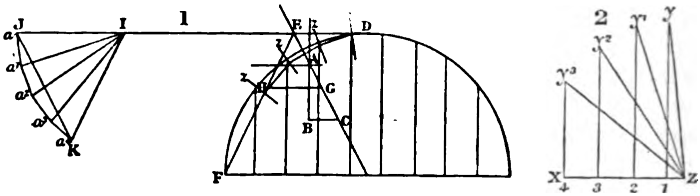
equal to the weights, and drawing lines a^1 G, a^2 G, &c., and a^1 H, a^2 H, &c., as for the previous examples.

Having considered the stability of arches under vertical loads, in which the horizontal pressure is the same throughout the curve, it will be necessary, before proceeding to investigate the stability of abutment walls, to inquire into the stability of arches which are acted upon by oblique pressures, and in which the horizontal thrust varies from point to point; not that such cases are of frequent occurrence in practice, but that it is necessary to the investigation of the stability of abutment walls.

Figs. 8 represent an arch acted upon by oblique pressures everywhere normal to the surface, as would be the case with fluid pressure; for simplicity, loads of uniform density have been considered as acting at each line *z*, *z*, *z*, &c.

Both sides of the arch being loaded symmetrically, and therefore

FIGS. 8.



the thrust at the crown being horizontal, it will only be necessary to draw the curve for one-half the arch. In this case the direction of the resultant of the loads acting at the centre of pressure will be inclined, to find which it is necessary to resolve all the oblique pressures into two others, horizontal and vertical.

Take any point Z (2 Fig. 8) and draw lines y Z, y^1 Z, &c., parallel to the pressures *z*, *z*, *z*, acting on the arch, commencing with the pressure nearest the crown, then by plotting the pressures on these lines (from Z upwards) with a scale of tons and letting fall perpendiculars y 1, y^1 2, &c., to the line Z X, the vertical and horizontal components of each pressure can be obtained with the scale.

To ascertain the point through which the oblique resultant passes, it is necessary to fix its horizontal distance and also its vertical height from the springing. To obtain the horizontal distance of the centre of pressure, moments must be taken with the vertical pressures round the abutment, and the sum of the moments must be divided by the total vertical pressure as for the previous examples.

The vertical height is also fixed by the same method, only in

this case multiplying the horizontal pressures by their vertical distances from the springing-line and dividing the sum of the moments by the total horizontal pressure; the two distances thus found when drawn on the diagram intersect at a point A (Fig. 8).

If the vertical pressure A B now be plotted from A downwards with a scale of tons, and a horizontal line B C be drawn measuring the horizontal pressure, a line drawn through the points A C will give the direction of the resultant and the length A C will measure its force.

The line of pressure D (at the crown of the arch) which is horizontal, can now be drawn, and from E where it intersects the resultant, draw the line E F, which gives the direction of thrust at the springing, and completes the curve of equilibrium for the resultant of the forces.

To find the thrust at the crown and springing, make E G equal to A C, and draw G H from G parallel to the thrust at the crown, then G H and H E represent the thrust at the crown and the springing respectively.

The force diagram for each weight acting separately, from which the curve of equilibrium is produced, is drawn by producing the line of thrust D at the crown to J, and making I J, J K and K I equal and parallel to G H, E G and E H respectively. Then by drawing lines $a\ a^1$, $a^1\ a^2$, &c., from J equal and parallel to the external pressures, commencing with the pressure nearest the crown, and joining the points a^1, a^2, &c., thus found with the point I, the lines a^1 I, a^2 I will be parallel to the various parts of the curve of equilibrium. This can now be constructed as in the previous examples, only taking care that the elements of the curve a I, a^1 I, &c., are drawn between the oblique lines z, z, z, &c., and not between the vertical ordinates, which in the previous examples indicated the direction of the pressures as well as the position of the loads.

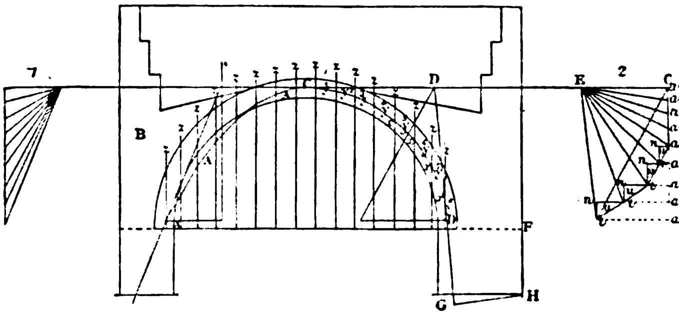
If the diagram is drawn correctly, the external forces $a\ a^1$, $a^1\ a^2$, &c., will join exactly at the two points J and K, and will therefore balance the resultant, and the line a^4 I, when drawn in the curve, will coincide with F E, the direction of the pressure at the springing. With a clear understanding of this last example, it will be a simple matter to investigate the stability of that portion of the abutment-wall above the springing of the arch, which in many cases may be unstable when the wall below the springing is quite strong enough, and under certain conditions with this in view it is necessary to make two separate calculations.

The foregoing examples have been given in order to demon-

strate an easy and ready method, which occurred to the Author, of proportioning the thickness of retaining walls to the thrust of arches when the curve of equilibrium for the vertical forces does not fall within the arch-ring.

Fig. 9 is an example of an arch which was built and failed soon after construction. In this case the wall below the springing is quite stable, while that portion of the wall above the springing is liable to be overthrown by the lateral pressure of the arch between the springing and the crown. By the following investigation the thickness of the wall necessary for such an arch may be easily calculated:—Diagram 1, Fig. 9, is the force diagram drawn from the actual vertical loads on the structure acting at *z*, *z*, *z*, &c., and A A A the corresponding curve of equilibrium. It will readily be seen that unless some extraneous force is acting

FIG. 9.



on the structure other than that due to the vertical load, the arch must collapse by being forced out between the haunches and the crown, owing to the curve of equilibrium falling considerably below the soffit of the arch at that point; it therefore becomes necessary to ascertain whether the lateral resistance opposed by the wall B between the springing and the crown is sufficient to resist the outward thrust of the arch.

As before stated the curve of equilibrium should fall within the middle third of the arch-ring, and it will generally be found that if a curve be drawn (for the dead load only) which practically coincides with the neutral line, the addition of the live load, will not cause the curve to fall without the proper limit; therefore instead of calculating the resistance of the wall shown in the diagram to ascertain whether it is sufficiently strong to overcome the resistance of the arch, the Author has assumed a curve which practically coincides with the neutral line, and by reversing the

order of the preceding calculations has arrived at the external forces required to balance such a curve, and by the resolution of forces has deducted the permanent vertical loads, thus leaving the forces which the wall has to resist.

The arch being loaded symmetrically and the thrust at the crown horizontal, draw a horizontal line C C, and produce D x (the direction of the thrust at the springing) until it cuts the line C C in D. There being no solid backing behind the first four divisions from the crown, no horizontal thrust can be transmitted, and the first four vertical loads will remain unaltered; therefore from any point E, draw lines E a^4 E t, &c., parallel to the lines y^4 y^5, &c., in the curve of equilibrium, omitting the first three from the crown; then by drawing C a^4 vertical and equal to the first four loads, at such a distance from E that it exactly fits between the lines E a and E a^4, the three lines which were at first omitted can be drawn from E to points a^1, a^2 and a^3, which measure the permanent loads on the first four divisions.

Let the line C a^4 be produced and divided into portions a^5, a^6, &c., equal to the remaining permanent vertical loads; and let horizontal lines be drawn from the points a^4, a^5, &c., until they cut the force lines in t t t, &c., then lines u u, &c., connecting these points will give the directions and amounts of the external forces necessary to maintain the assumed curve of equilibrium.

As there are only vertical loads on the arch and it will be more convenient to calculate the strength of the wall to resist horizontal pressures, it will be necessary to resolve all the oblique forces into two others, vertical and horizontal.

The parallel lines a^5 t, a^6 t, &c., being drawn from the points a^5, a^6, &c., the distances between which on a scale of tons measure the pressure of each permanent vertical force already on the arch, lines drawn vertically from the points of intersection t t t, &c., to the next horizontal line above, will also measure the pressure of the respective loads, and will therefore be the vertical components of the oblique forces to which they correspond; and the lines n t, n t, &c., which complete the triangles of force will measure the horizontal components, all the vertical forces can therefore be disregarded as not entering into the calculation, being supplied by, and made equal in the force diagram to the weight of, the structure.

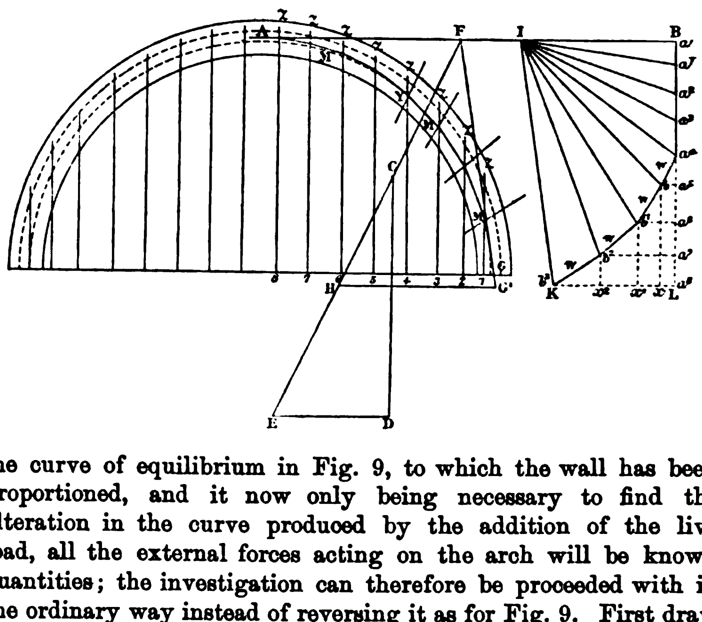
The resistance of the arch to be overcome is now all horizontal, and equal to pressures n a^4, n t, &c., acting at the points x, x, x, in the arch; and the thickness of the abutment-wall at the springing should be such that the sum of its moments, that is, its weight

multiplied by the distance of its centre of gravity from point F (the thickness of the wall being fixed tentatively), should be equal to the sum of the moments of the forces $n\,a^4$, $n\,t$, &c., about the springing. By these calculations it will be seen that the thickness of the wall for the arch referred to should have been 6 feet 3 inches at the springing.

It has been previously stated that if the curve of equilibrium for the dead load of an arch practically coincided with the neutral line, the curve for the dead load and live load together would generally fall within the middle third, and a reference to Fig. 10 will prove the truth of this statement relative to the structure under examination.

Having obtained the necessary horizontal resistance, to maintain

FIG. 10.



the curve of equilibrium in Fig. 9, to which the wall has been proportioned, and it now only being necessary to find the alteration in the curve produced by the addition of the live load, all the external forces acting on the arch will be known quantities; the investigation can therefore be proceeded with in the ordinary way instead of reversing it as for Fig. 9. First draw A B horizontal from the crown of the arch, then by plotting the horizontal and vertical distances of the resultant from the abutment, which will be found as before by taking moments with the vertical and horizontal forces, and from the point C so found plotting the total vertical load C D, and from D to E the total horizontal force, a line joining C E will give the direction and amount of the resultant, which if produced to F, a line joining

F G will give the direction of the thrust at the springing. From the point F mark off F H equal to C E, and from H draw H G^1; then H G^1 and G^1 F will measure the forces at the crown and the springing respectively, and by setting off from B — B I equal to H G^1, and I K equal and parallel to F G^1, the force diagram can be constructed in the following manner: Draw the line B L equal to the vertical forces (that is, the sum of the dead and of the live loads) and divide it into parts $a\,a^1$, $a^1\,a^2$, &c., respectively equal to the dead and the live load acting at the points in the curve z, z, z, &c.; next draw $a^5\,b$, $a^6\,b'$, &c., horizontal, making $a^8\,b^3$ equal to the sum of the horizontal forces (which will be the same as for Fig. 9), and divide it into parts L x, L x^1, &c., each equal to the horizontal forces, commencing with L x, which should be equal to the horizontal force acting at Y; then lines drawn vertically upwards will cut the lines $a^5\,b$, $a^6\,b'$, &c., at points $b\,b^1$, &c., lines w, w, w, w, connecting which will give the oblique resultant pressures from the horizontal and the vertical components.

If the diagram is drawn correctly the point b^3 should exactly coincide with the point K; lines I a^1, I a^2, &c., and I b and I b^1, &c., will now give the elements of the curve M M M, which it will be seen just falls within the middle third indicated by the two dotted lines in the arch-ring.

In describing this curve as in Fig. 8, when the point Y is reached care must be taken to draw the elements of the curve between the oblique lines indicating the direction of the pressure, which should be made parallel to the lines w, w, w, w, before drawing the curve.

In the above example a live load of uniform density and equally distributed over the whole of the arch has been taken; for as the traffic traversed the arch longitudinally, it would be highly improbable that one half of the arch would have its maximum live load while the other half would be free from load, as would be the case when a crowd of people or a regiment of soldiers were crossing an arch with its axis at right-angles with the line of traffic.

Although by these calculations it appears that the walls of the arch referred to should have a thickness of 6 feet 3 inches at the springing, it is not to be understood that the arch would collapse if they were of lighter construction.

Many arches have been constructed and are still standing without signs of failure, in which the curve of equilibrium is considerably outside the middle third, and if these calculations had been made, giving a wider limit for the curve, it would have been

found that walls of lighter construction would have balanced the arch; but as the limit taken in this Paper has been proposed by such an authority as Rankine there is good reason for adopting it, and as the walls only just balance the curve by keeping it within that limit a margin of safety is allowed for.

The stability of arches and of the walls retaining them having been considered down to the springing-line, it now becomes necessary to investigate that portion of the abutment-wall below the springing.

In arches such as Fig. 9, where the curve of equilibrium is kept in position by the wall above the springing, the thrust of the arch at the abutment, together with the resultant of the upper wall, must be overcome by the moment of the wall below the springing, the stability of which is not augmented by the upper portion, as that is already in use in balancing the curve.

Fig. 11 represents an abutment wall, where no horizontal pressure is exerted against the upper wall. Through the centre of gravity of the wall draw A B, and from point C, where it intersects the line of thrust, make C D equal to the thrust of the arch, and draw D E vertical and equal to the weight of the wall; then E C will measure the direction and amount of the resultant. If the resultant falls within the base of the wall, it will be stable, and if outside, as in Fig. 12, it will cause the wall to overturn. To prevent putting too much pressure on the outside of the wall (which might crush the material), and also to ensure sufficient stability, the resultant should in all cases fall considerably within the base of the wall.

The lower portions of abutment-walls of arches, such as are indicated in Fig. 9, where the wall above the springing is utilized in maintaining the curve of equilibrium, can best be treated by moments.

If, as in this Paper, the walls are designed to exactly balance the pressures of the arch (any factor of safety being added after if required), the horizontal pressure overcome by the wall, which is indicated by line $t\,a^8$ in the force diagram, will be transmitted to point F, round which moments have been taken; also the vertical forces; but as point F will fall vertically over the point G, round which moments must be taken for the lower portion of the wall, the vertical forces will produce no effect. Therefore disregarding the weight of the wall above F, the weight of the wall between F and G, multiplied by the distance of its centre of gravity from G, and added to the force D D multiplied by its leverage G H (which is drawn at right angles to D D through

point G), should be greater than the horizontal force $t\,a^3$ multiplied by its leverage F G. Fig. 9 will be found to amply satisfy this condition.

In arches such as Fig. 5, where the curve of equilibrium (from the vertical load alone) falls within the arch-ring, any wall that may be above the springing will have to sustain no lateral thrust from the arch, and will therefore augment the stability of the lower portion. In such cases, instead of calculating only that portion of the wall below the springing to resist the thrust of the arch, the whole of the wall from top to bottom will enter into the calculation.

Throughout the various investigations in this Paper, no allow-

Fig. 11.

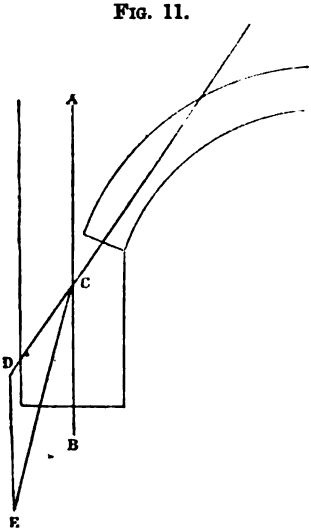
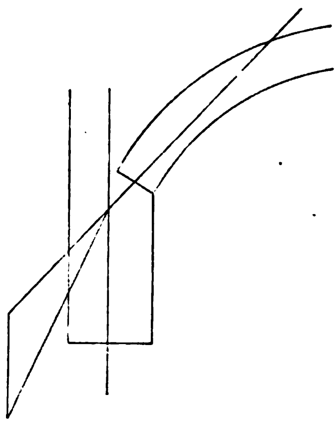


Fig. 12.



ance has been made for the cohesive strength of mortar or cement, which is undoubtedly the general rule; but in comparing the results obtained for the thickness of abutment-walls by the method of Mr. W. H. Barlow, Past-President, Inst. C.E.[1] with the results obtained by the method advocated in this Paper, a very important difference arises.

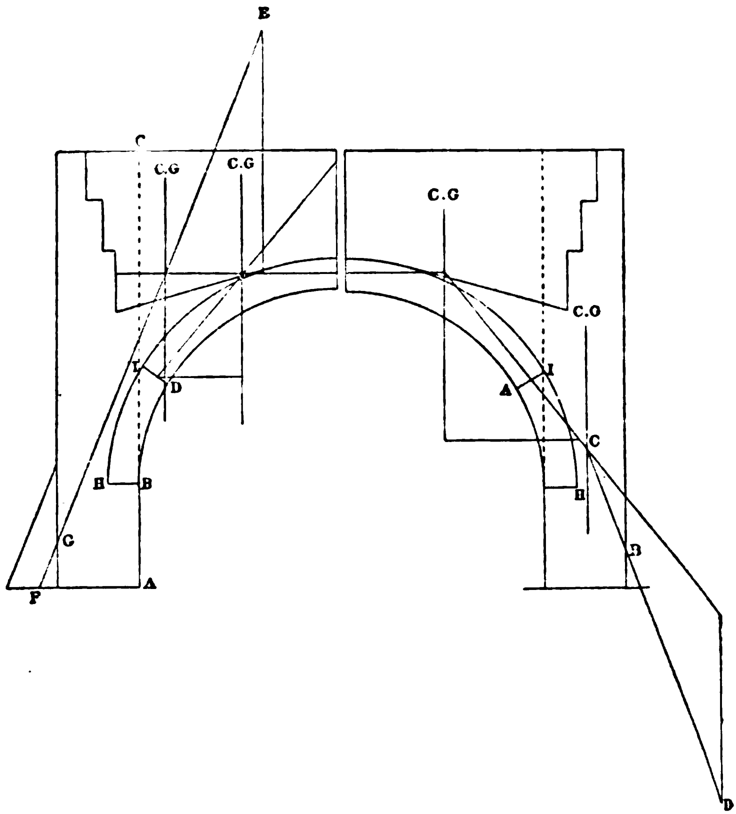
The portion of the arch which falls within the vertical line A B produced to C, Fig. 13, is assumed by Mr. Barlow to form part of the abutment, the arch is therefore considered as springing from D, and the line of thrust tending to overturn the abutment

[1] Minutes of Proceedings Inst. C.E., vol. v. p. 162.

is indicated by E F, which would cause the abutment to be overthrown immediately below point G. The graphic method used for this Fig. will be found in Mr. Barlow's Paper, and therefore will not need explanation.

Starting on the same basis; that is, considering the arch to spring from A, Fig. 14, and using the method advocated by the

Fig. 13. Fig. 14.



Author, it will be seen that exactly the same result is arrived at, and that the point B, where the line of thrust C D cuts the outer side of the abutment, is exactly the same distance from the springing line as point G in Fig. 13.

If the arch below A is considered as part of the abutment, Fig. 15 will indicate the way in which failure would take place; but as there is no bond along the joint H I, it will readily be seen that such a condition of failure must entirely depend upon the

cohesive strength of the mortar or cement firmly uniting that portion of the arch to the abutment.

By disregarding any assistance from the mortar or cement, failure can take place in no other way than that indicated in Fig. 16; and instead of the whole mass turning about one point C, the arch will turn about a point D, and the wall about a point

FIG. 15.

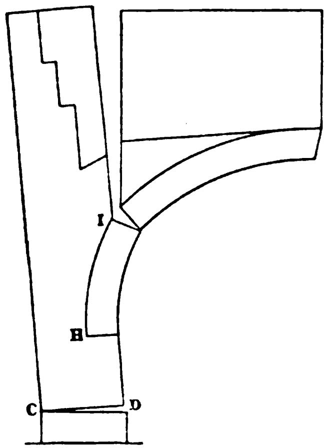
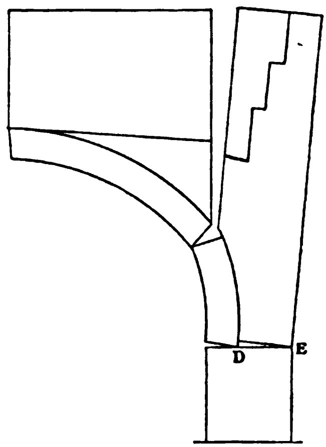


FIG. 16.



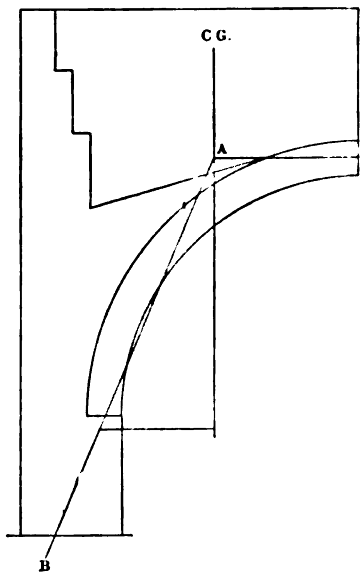
E, thus reducing the leverage, which will also cause the moment of resistance to be reduced.

Referring to Fig. 17, which is calculated by the method advocated by the Author, it will be seen that the line of thrust A B of the arch, without taking into account the weight of the abutment, falls within the base of the wall, and as the arch and the loads are the same for Figs. 13, 14, and 17, it might be expected that the lines of thrust in both would be identical; but then Fig. 17 is calculated without any allowance being made for the cohesion of the mortar, and therefore the calculations are made from the true springing of the arch; whereas in Figs. 13 and 14, the arch is assumed to spring from the points D A, and the cohesion of the mortar is taken into consideration along the joint H I.

Although in Fig. 17 the line of thrust falls within the base, by completing the investigation as in Fig. 9 it would be found that the wall was not stable above the springing, and would have to be increased in thickness to ensure equilibrium; whereas by Mr. Barlow's method the structure apparently could be rendered perfectly stable by making an addition to the bottom of the wall, as shown in Fig. 13.

Throughout the investigation in Mr. Barlow's, Mr. G. Snell's,[1] and other Papers, no allowance has been made for the adhesion of the mortar in the bed-joints, such as C D, Fig. 15; but where the line of thrust falls outside the wall, it has been considered necessary to so alter the design as to prevent such occurring; and why the

FIG. 17.



tenacity of the mortar should be considered in one part of a structure, and not in another becomes an important question.

In preparing this Paper, the Author has not assumed that failure would take place in the manner shown in Fig. 16; but by the careful investigation of a fallen structure, in which the mortar inside the walls had not set at the time of the failure, he has ascertained beyond a doubt that failure took place as indicated.

The Paper is accompanied by numerous diagrams, from which the Figs. in the text have been prepared.

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[1] Minutes of Proceedings Inst. C.E., vol. v. p. 439.

(*Students' Paper, No. 212.*)

"Experiments on the Relative Strength of Cast-Iron Beams."[1]

By Edward Carstensen de Segundo, and Leslie Stephen Robinson, Studs. Inst. C.E.

It is evident that, after the exhaustive labours of Messrs. Barlow, Hodgkinson, and others, the effect of any experiments designed only to measure the strength of cast-iron beams of well-known sections would be merely to multiply examples and not to introduce anything new. It is hoped by the Authors that they are guilty neither of presumption nor of ignorance of existing authorities in instituting these experiments, inasmuch as their object is not so much to determine the absolute strength of the pieces, as to compare the behaviour of the beams under similar conditions; and to determine, among other things, if theory is right in asserting that certain changes of form of the section can be made without affecting the strength or general behaviour of the beam. For example, according to theory[2] a beam of hollow circular section ought to give results identical with those of a beam having the same sectional area, the form of the section, however, being arrived at by massing up the metal of the hollow cylinder about a diameter parallel to the line of application of the load. Also, the double tee-section (C) ought to behave in the same way as the box-section (E).

The different sections experimented upon were the following:— The small double tee-section (C) is to compare with the box-section (E), the box-section being arrived at by dividing the web and placing one-half to form each of the vertical sides of the box.

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[1] This Paper was read at a meeting of the Students on the 16th of April, 1886.

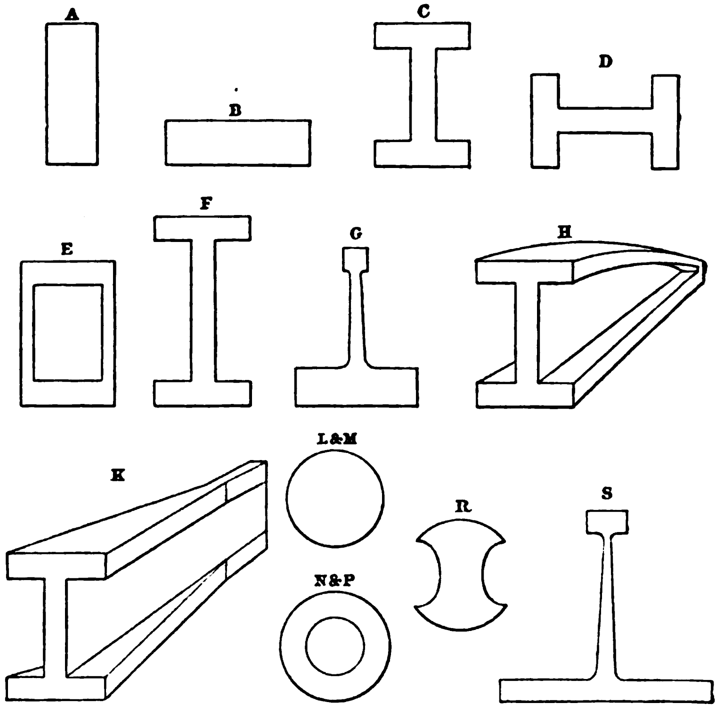
[2] The Authors wish it to be understood, that in speaking of theory, they mean theory as far as mathematicians have succeeded in employing it. For theory is to practice what algebra is to geometry, and there can be no doubt that, were the theory of any subject complete, it would be possible not only to account for, but to calculate and be ready for, every incident that could occur in the practical working of that subject.

The solid circular sections L and M (L being turned in order to remove the skin) compare with—

(1) The hollow circular sections N and P (P being turned in order to remove the skin).

(2) The hollow cylindrical section massed up about a diameter parallel to the line of application of the load (R).

Fig. 1.



Upwards of sixty pieces were cast of the various sections just alluded to, and also ten test-pieces, 15 inches long and $1\frac{1}{4}$ inch in diameter, for the determination of the specific extension, specific compression, and crushing load of the material. All the pieces were, of course, cast from the same ladle, and, with the exception of three 36 inches by 1 inch by 1 inch bars, all were cast on end.[1]

[1] This cast-iron was composed of:—1 part Damelton, 5 parts best scrap.

All the beams, except those marked F and S, were designed to have a sectional area of 3 square inches.

Ten beams were rectangular in section (A and B), six were tested as they came from the foundry, and four were planed all over so as to remove the skin.

Three, four, or five of each of the other sections were cast, and one specimen of each section was kept in reserve until the Authors had satisfied themselves that any apparently abnormal results were really due to the form of the bar, and not to the quality of the casting.

A special allowance was made in the patterns of those beams which were to be machined (A, B, L, P), so that ultimately the sectional-area of these beams was the same as that of the unmachined ones.

Two beams were designed to have a constant strength along the whole span. This result was arrived at in two different ways:—

(1) By varying the depth (H).

(2) By varying the breadth (K).

The dimensions of the beam marked S are reduced from those of the beam found practically to be the strongest of the double tees with unequal flanges by Mr. Hodgkinson.

As regards the theoretical shape of the double tee-section, it might be interesting to point out one or two details.

If the assumptions upon which the beam theory is founded are admitted as correct, it can be shown mathematically that, in order to dispose of the metal in the best way, it must be so arranged that the neutral-axis divides the depth in the ratio of the breaking-stress in tension to the breaking-stress in compression, and if the area of the web is neglected, the areas of the flanges must also be in this proportion.

The actual form of this section, arrived at by purely theoretical investigations, is due to Professor Karl Pearson, M.A., LL.B., of University College. Mr. Pearson finds that section to be theoretically the strongest in which not only are the before-mentioned conditions fulfilled, but where also the difference in the thicknesses of the upper and the lower flanges is as great as possible. This means, in mathematical language, where the upper flange has a finite and the lower an infinitely small thickness, or where the one has a finite and the other an infinitely great thickness.

All the pieces to be subjected to transverse-stress were provided with small faces at suitable points. These faces were planed true, and afforded proper bearings for the knife-edges of the testing-machine.

The whole of the experiments were made in the Engineering Laboratory of University College, Gower Street, with one of Greenwood and Batley's 100,000 lbs. horizontal testing-machines.[1] It is needless to go into any detail concerning this machine, as it has now become well known, although the particular machine referred to here was the first of its type, and was especially constructed for Professor Alex. B. W. Kennedy, M. Inst. C.E., by the above-mentioned firm. The load is applied by a hydraulic ram, and balanced by a dead weight. The machine has been frequently calibrated and found to be correct.

The tensile- and the compressive-strains, as well as a large number of deflections, were measured by an ingenious mechanism, the design of Professor Kennedy, which has been fully described and illustrated by Mr. P. V. Appleby, Stud. Inst. C.E., in a Paper on "Experiments on iron and steel."[2] As this gear is of rather delicate construction, and could not be left on the piece until fracture occurred, and as it was desirable to measure the deflection at the instant of fracture, another gear was contrived by the Authors for the purpose. It consists of a pointer A B (Fig. 2), one end A of which is kept lightly pressing on the beam at the centre of the span; the other end B holds a pencil, which rests on the surface of a piece of prepared paper stretched on a drum, the axis of which is at right angles to the mean position of the pointer. It has been mentioned before that the pull of the hydraulic ram is balanced by a dead weight. This weight is attached to a carriage, which runs along a steel-yard; thus the position of the carriage at any moment is proportional to the load, and therefore to the stress at that moment. A fine strong silk cord was attached to the carriage, was next passed round the two pulleys E and F, and was then allowed to hang freely, a small weight being attached to the end by an elastic band, in order to secure as nearly uniform tension as possible throughout the whole length of the cord. Both the spindles G and S, as well as the pivot of the pointer, moved on centres, which were rigidly connected to the cross-head of the machine. Thus, as the load on the beam increased, the end B of the pointer moved nearly parallel to the axis of the drum, while the motion of the carriage on the steel-yard caused the spindle G to rotate, which rotation was communicated to the drum by means of the silk band K. In this way a

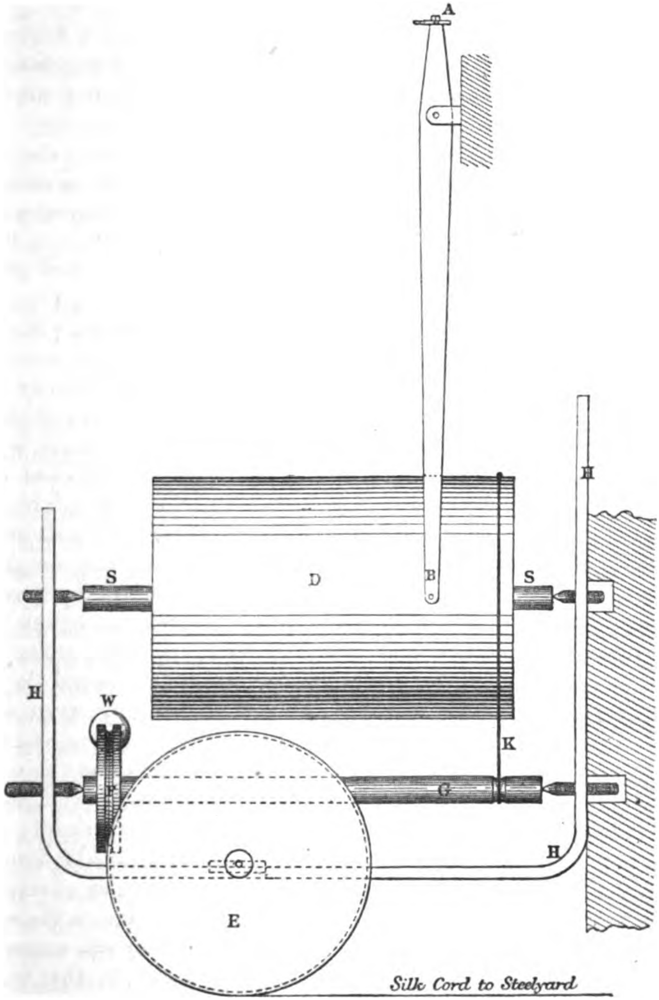
[1] For description of this machine see "Engineering," of the 26th of September, 1879.

[2] Minutes of Proceedings Inst. C.E., vol. lxxiv. p. 258.

curve was drawn upon the paper on the drum, more or less steep, according to the stiffness of the beam.

At the instant of fracture the pointer was jerked suddenly for-

Fig. 2.



ward, showing a distinct break in the curve, thus enabling the deflection at that point to be measured with considerable accuracy.

The method adopted in testing the specimens was to strain them

between two limits until the set was practically eliminated, and then a series of readings was taken from which calculations were made. The beams were all tested on a span of 20 inches, and the load was applied at the centre.

The results are fully recorded in the Tables which accompany this Paper, and it will only be needful to touch upon one or two details.

The results of the machined beams of rectangular section (A and B) are confirmatory of the law that the breaking loads of beams vary as the square of the depth and as the breadth. The four planed-up specimens were 2·93 inches by 0·9 inch, therefore A was 3·26 times as deep as broad, and B was 3·26 times as broad as deep. Hence the breaking-load of A ought to be equal to the breaking-load of B $\times \frac{(3\cdot26)^2}{3\cdot26}$, or A's breaking-load ought to be 3·26 times as large as B's. The mean breaking-load of the machined A's was 4·82 tons, and of the machined B's 1·50 ton, and $\frac{4\cdot82}{1\cdot50} = 3\cdot21$, which practically agrees with 3·26.

The reason of this law is readily understood on considering the resisting efficiency of these sections as determined graphically. (For an explanation of the graphic method see Appendix.)

If a beam be twice as deep, but of the same breadth, as another, not only is the area of the equivalent figure doubled, but the arm of the resisting couple is also doubled; hence the beam becomes $2 \times 2 = 4$ times as strong when the depth is doubled without altering the breadth. Now suppose the breadth to be doubled while the depth remains unaltered, then the area of the equivalent figure is doubled; but the arm of the resisting couple is not altered, hence it becomes only twice as strong when the breadth is doubled.

The results of the double tee (C) tested upright and on its side (D) show clearly the greater resisting efficiency of the material when placed at as great a distance as possible from the neutral axis. The double tee (C) broke under 2·63 times as great a load as D, and was considerably stiffer. It is difficult to state what is the depth, and what the breadth of such sections as these; and it seems not unreasonable to consider the mean breadth of the equivalent figure (see Appendix), and the arm of the couple of internal resistance, as the equivalents of the breadth and the depth of the section. Unfortunately, it is impossible to test the accuracy of this suggestion by a comparison of the results given by these particular pieces, as several of them exhibited very unsound fractures. But in former experiments on the transverse strength

of various materials the Authors tested some beams of similar sections, and an examination of the results then obtained will serve to determine the point.

On a span of 20 inches the double tee broke at 9,500 lbs. on the centre of the span, and the double tee tested on its side broke with a load of 2,190 lbs., or about $\frac{10}{43}$ of the breaking-load of the first. On a span of 9 inches the respective breaking-loads were 28,440 lbs. and 5,760 lbs., the double tee when on its side breaking with about one-fifth the load it could bear when upright. These results show the double tee upright to be nearly five times as strong as the double tee on its side.

Now the mean breadth of the equivalent figure of the double tee upright was 0·5 inch, and the arm of the couple of internal resistance was 1·88 inch. The respective values of these quantities in the other beam were 0·5 inch and 0·84 inch. Hence the breaking-loads ought to be in the ratio $\left(\frac{1\cdot 88}{0\cdot 84}\right)^2 \times \frac{0\cdot 5}{0\cdot 5} = 5\cdot 00$, which is practically correct.

The behaviour of the double tee (C) and the box-section (E) shows that, as far as this modification of the form of the section is concerned, the theory is correct that the strength of the beam remains unaltered, of course within the limits of reasonable design. They are equally stiff, equally strong, yield the same transverse modulus, and behave generally in the same way under stress.

The results given by the beams designed to have constant strength throughout the whole span (H and K), (1) by varying the breadth only (K), (2) by varying the depth only (H), show equal stiffness in both sections, and equal values of the ratio of the breaking-load to the weight of the beam.

Owing to practical considerations, the ends of the parabolic girder became much stiffer than they ought to have been; thus these two beams cannot be said to compare satisfactorily one with the other.

The behaviour of those beams of circular section, and its modifications (L, M, N, P, R), may be compared with considerable accuracy, inasmuch as their sectional-areas varied only to the extent of about 3 per cent. from the area for which they were designed, namely, 3 square inches. For convenience in reference, the solid circular section will be denoted by M; solid circular turned, in order to remove the skin, L; hollow circular section, N; hollow circular section turned, P; hollow circular massed up about a diameter parallel to the line of application of the load, R.

Of these five, M shows the lowest mean breaking-load, but M

and L are very nearly equal as regards strength. L shows a higher ultimate deflection, due possibly to the fact of the skin having been removed, which circumstance would naturally render the outer fibre more free to extend. The same thing is noticed in the behaviour of P, but it is not so marked as in the case of L.

The stiffness of M and N are about the same, but the breaking-load of N is higher than that of M, which is only to be expected, the metal being more advantageously placed in N than in M.

L and P show a similar difference, but not quite so marked, possibly because the ratio of the depth of the skin to the total depth of the beam is not so large in P as in L.

R has a lower mean breaking-load than either P or N, the progression being $N > P > R$, but, on the other hand, R is decidedly stiffer. This may be due to the fact of the shape of the section approaching somewhat to the form of a double tee.

Theoretically, that is so far as theory is employed, N, P, and R, ought to be identical in their behaviour. Practically, however, they differ in strength and in stiffness.

Calling the breaking-load of N unity,

$$N = 1 \cdot 000$$
$$P = 0 \cdot 908$$
$$R = 0 \cdot 872$$

the breaking-loads being in each case the mean of the results given by three beams exhibiting sound fractures.

The order of stiffness (calculated from the ultimate deflection) is:—

$$R = 1 \cdot 000$$
$$N = 0 \cdot 793$$
$$M = 0 \cdot 763$$
$$P = 0 \cdot 730$$
$$L = 0 \cdot 574$$

The order of values of ratio $\frac{\text{breaking-load}}{\text{weight of beam}}$ is:—

$$N = 1 \cdot 000$$
$$P = 0 \cdot 920$$
$$R = 0 \cdot 850$$
$$L = 0 \cdot 695$$
$$M = 0 \cdot 654$$

This shows that of these five sections N behaves on the whole in the most satisfactory manner, exhibiting the highest breaking-

load, and the highest value of the ratio of the breaking-load to the weight of beam, and being second in order of stiffness.

In small structures, where the depth of the skin bears an appreciable ratio to the total thickness of the piece, the skin materially enhances the ultimate strength. The results of the pieces tested with and without the skin are given below.

The modulus of elasticity in tension is denoted by E_T, and that in compression by E_C:—

$$\left.\begin{array}{l} E_C \\ E_T \end{array}\right\} \text{obtained from test-pieces with the skin . . .} \left\{\begin{array}{l} = 15570000. \\ = 13950000. \end{array}\right.$$

$$E_C = 1 \cdot 116\, E_T.$$

$$\left.\begin{array}{l} E_C \\ E_T \end{array}\right\} \text{obtained from turned test-pieces . . . .} \left\{\begin{array}{l} = 13900000. \\ = 12470000. \end{array}\right.$$

$$E_C = 1 \cdot 114\, E_T.$$

$$E_C \text{ with skin} = 1 \cdot 12\, E_C \text{ without.}$$
$$E_T \text{ with skin} = 1 \cdot 1187\, E_T \text{ without.}$$

It appears from this that the modulus in compression is about 12 per cent. higher than the modulus in tension under both conditions, that is, with skin and without; but that the respective values of E_C and E_T are smaller when obtained from test-pieces with the skin removed.

It appears also that the skin influences the ultimate transverse strength.

The mean breaking-load of A_{14} and A_{15} reduced to the mean area of A_{11} and A_{12} is 5·83 tons.

The mean breaking-load of B_{14} and B_{15} reduced to the mean area of B_{11} and B_{12} is 1·77 ton.

The mean breaking-load of A_{11} and A_{12} = 6·6 tons.

Do. do. B_{11} and B_{12} = 2·11 tons.

Ratio of non-machined to machined in first case $= \dfrac{6 \cdot 6}{5 \cdot 83} = 1 \cdot 13.$

Ratio of non-machined to machined in second case $= \dfrac{2 \cdot 11}{1 \cdot 77} = 1 \cdot 19.$

It might perhaps be not uninteresting to consider the tendency of the results of these experiments with regard to the ordinarily accepted theory, by means of which the stresses in a beam are commonly calculated. The following remarks, it must be understood, apply solely to cast-iron.

This theory is based upon the assumption—

(1) That the stress varies directly as the distance from the neutral-axis.

(2) That the tensile-modulus is equal to the compressive-modulus.

(3) That every plane section of a beam remains a plane section after flexure.

(4) That the shear is inappreciable.

Now formulae based on these assumptions give values which agree very fairly with values obtained by experiment, as long as the load on the beam is well within the maximum load that the piece will bear. When, however, the load approaches the breaking-load, values of the deflection obtained from the formulae are no longer reliable; they are smaller than those actually measured. The ultimate tensile-stress on the outer fibre calculated from the formula: bending moment = stress $\times \frac{I}{y}$ (where I = moment of inertia of section, and y = distance of the outer fibre from the neutral axis) is invariably greater than the ultimate breaking-stress obtained from a bar pulled asunder in direct tension. (For convenience in future reference this ratio will be called $\frac{\text{breaking-stress from beam}}{\text{breaking-stress from test-piece}} = \theta$.)

Now, of course, the question arises, does this abnormal stress really exist in the outer fibre, or is it only an inaccurate result brought about by mathematical reasoning based on insufficient premises?

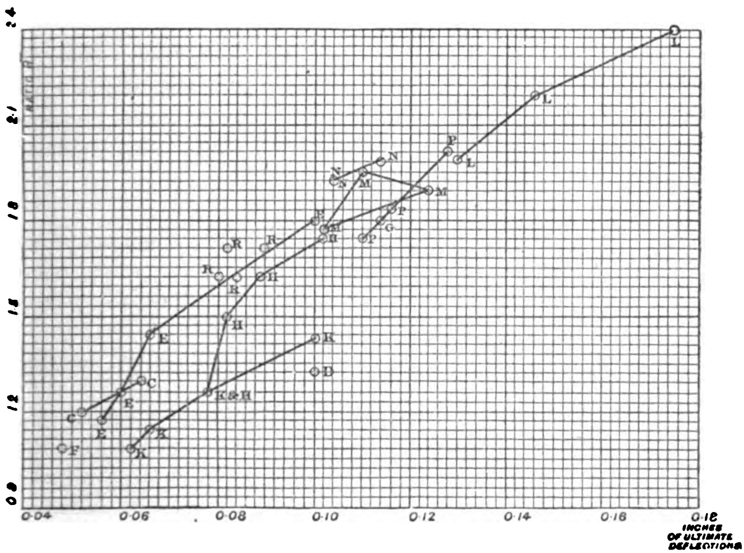
If the assumptions are not of themselves sufficiently incorrect to account for so large a discrepancy as is sometimes exhibited—and it is probable that tho Authors are justified in taking this view, the cause of this discrepancy must be sought in the existence of other sources of strength, left out of account in the ordinary calculations, and in the fact that the tensile-modulus of cast-iron decreases as the stress increases. The tendency of these results is to show that this discrepancy decreases as the stiffness increases, that is, those sections which were relatively the stiffest show the least ratio θ. Individual pieces of the same section show also a variation of θ in the same direction as the stiffness. In Fig. 3 the values of ratio θ are plotted to a horizontal scale of maximum deflections, and a line drawn through these points so as to take an average, as it were, is nearly straight and rises gradually. Of course it is now impossible to estimate how much of these ultimate deflections was set, but still from the general behaviour of the pieces, and from the results of other experiments, it appears highly probable that the ratio θ varies in the same direction as the relative stiffness. Thus it might be concluded that, collectively, these

sources of strength, and the relative stiffness or the deflection, are functionally connected.

It is certain that the tensile-modulus of cast-iron decreases as the stress increases. This is shown by the results of Mr. Hodgkinson's experiments on the tensile-strength of cast-iron, and is corroborated in some very careful determinations of the extension of cast-iron under increasing loads by Professor Kennedy.

It is also not unreasonable to suppose that a fibre, by virtue of its being molecularly connected to less strained material, becomes capable of enduring a greater stress without breaking than if it were pulled in direct tension.

FIG. 3.



Then again the results of experiments, carried out by Professor Kennedy, with a view to measure the change of angle of the corners of a beam when bent, point to the fact that originally square corners do not remain square after flexure. The change of angle is, however, not sufficiently great to account for the discrepancy.

It must not be forgotten that the ordinary beam theory is a greatly simplified form of a complex problem, for it only takes account of the horizontal and the vertical components of the many stresses existing in a beam when loaded.

Taking these things into consideration, it may be concluded

that, at all events, it is known in what direction to look for a means of clearing up this difficulty, but, at the same time, the means may be of so complex a character, involving the use of so high mathematical reasoning, as to render it doubtful whether the end justifies the means; and whether it would not be more advisable, at least for practical purposes, to introduce an empirical coefficient in the formulae, which would allow for the stresses acting along the principal axes, the change of modulus, &c., and so give approximately correct values.

The Authors wish to express their great indebtedness to Professor Kennedy for the interest manifested by him in these experiments, and for many valuable suggestions as regards the method of testing the specimens.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been prepared.

APPENDIX.

RESULTS of EXPERIMENTS ON TEST-PIECES.

No.	Description.	Area in Square Inches.	Specific Extension in 1,000ths of an Inch.	Specific Compression in 1,000ths of an Inch.	E_T lbs. per Square Inch.	E_C lbs. per Square Inch.	Breaking-Stress. Tons per Square Inch.
10	With skin .	1·112	0·730	0·650	13,700,000	15,400,000	..
10	Turned . .	0·967	0·788	0·687	12,700,000	14,500,000	11·82
11	With skin .	1·090	..	..	..	..	..
12	„ .	1·090	0·625	..	16,000,000	..	11·50
13	„ .	1·100	0·633	..	15,800,000	..	..
13	Turned . .	0·862	0·644	..	15,530,000	..	11·85
14	With skin .	1·149	..	..	..	..	11·45
15	„ .	1·150	0·687	0·625	14,550,000	16,000,000	..
15	Turned . .	0·790	0·850	0·834	11,700,000	12,000,000	10·20
16	With skin .	1·120	very unsound			..	..
17	„ .	1·160	..	..	..	..	10·60
18	„ .	1·149	0·746	0·632	13,400,000	15,800,000	..
18	Turned . .	1·000	0·760	0·655	13,180,000	15,200,000	10·04
19	„ . .	0·862	0·770	..	13,000,000	..	11·40

Mean breaking-stress with skin . . . . . = 11·18 tons per sq. in.
„ „ without „ . . . . . = 11·06 „ „

Mean modulus in tension = E_T . . . = 14,680,000 lbs. per sq. inch.
„ in compression = E_C . = 15,000,000 „ „

Crushing-load of struts, 2 inches long and 0·86-inch diameter = 68,600 lbs. = 53 tons per square inch.
Crushing-load of a similar piece = 66,500 lbs. = 50 tons per sq. in.

Both these pieces were cut from test-pieces which had been broken in tension.

RESULTS of EXPERIMENTS on BEAMS.

No.	Description.	Area in Square Inches.	Z.	Deflection at calculated stress of 10,000 lbs. per Square Inch on Outer Fibre.		Breaking Load.		Breaking Stress in Tons per Square Inch.	Ultimate Deflection in Inches.	Transverse Modulus in lbs. per Square Inch.	Br'king Load / Weight.	θ.	Fracture.
				Deflection in Inches.	Load at Centre in lbs.	Lbs.	Tons.						
A_{11}	Rect.	3·2	1·627	0·015	3,250	14,780	6·6	20·3	0·074	14,660,000	869·4	1·815	Sound.
A_{12}	”	3·05	1·55	..	..	10,400	4·64	14·99	0·0804	..	630·0	1·33	Small blow-holes on tension side.
A_{14}	” planed	2·63	1·287	..	..	10,960	4·89	19·00	0·104	11,800,000	776·0	1·719	Perfectly sound.
A_{15}	” planed	2·63	1·287	..	..	10,660	4·76	18·50	0·0834	13,200,000	754·0	1·67	Perfectly sound.
B_{11}	Rect.	3·121	0·5304	0·0436	1,060	4,680	2·09	19·7	0·204	14,520,000	279·0	1·76	Sound.
B_{12}	”	3·255	0·5693	..	..	5,580	2·49	21·89	0·2107	..	318·0	1·96	Sound.
B_{13}	”	3·055	0·5092	..	..	3,920	1·75	17·14	0·188	15,500,000	230·5	1·53	Sound.
B_{14}	” planed	2·63	0·395	..	..	3,415	1·52	19·3	0·269	16,100,000	239·0	1·74	Sound.
B_{15}	” planed	2·63	0·395	..	..	3,335	1·49	18·8	0·2906	13,830,000	235·0	1·70	Sound.
C_{11}	..	3·407	2·59	0·0172	5,186	16,680	7·44	14·36	0·064	12,300,000	953·3	1·285	Unsound.
C_{12}	..	3·389	2·68	..	..	16,350	7·3	13·6	0·0521	12,000,000	921·0	1·217	Cinder-flaw and blow-hole.
D_{13}	..	3·266	0·995	..	..	5,160	2·30	11·57	0·0792	12,400,000	341·0	1·035	Blow-hole in compression flange.
D_{14}	..	3·506	1·12	0·034	2,135	7,380	3·29	14·70	0·099	11,200,000	410·0	1·315	Perfectly sound.
E_{11}	..	3·193	2·265	..	..	16,300	7·27	16·05	0·066	..	1,015·0	1·43	Not very sound.
E_{12}	..	3·01	2·214	0·018	4,430	20,050	8·95	20·20	0·101	12,830,000	1,234·0	1·805	Blow-hole in compression flange.
E_{13}	..	2·94	2·176	..	..	13,620	6·08	14·00	0·0598	..	864·4	1·25	Sound.
E_{14}	..	2·95	2·22	..	..	13,050	5·82	13·12	0·0557	..	803·3	1·17	Not very sound.
E_{15}	..	3·119	..	..	..	..	5·00	..	..	..	..	..	
F_{11}	..	3·378	3·588	..	..	..	..	..	..	..	..	..	
F_{12}	..	3·338	3·635	0·0146	7,270	19,440	8·68	12·00	0·0479	..	1,143·0	1·074	Unsound.
F_{13}	..	3·44	3·7	..	..	16,560	7·39	10·00	0·0406	11,150,000	946·0	0·895	Very unsound.

F_{14}	..	3·447	3·69	..	..	21,600	9·64	13·03	..	..	1,250·0	1·165	Unsound.
G_{11}	..	3·08	..	..	..	19,260	8·6	17·2	0·105	..	1,130·0	..	Very unsound.
G_{12}	..	3·179	..	..	..	21,190	9·46	20·04	0·115	..	1,240·0	1·79	Perfectly sound.
G_{13}	..	3·12	2·50	0·022	2,500	21,750	9·71	19·42	0·116	15,100,000	1,280·0	1·73	Quite sound.
H_{11}	..	3·41	2·527	..	..	21,950	9·8	19·6	0·103	..	1,510·0	1·75	Quite sound.
H_{12}	..	3·43	2·568	..	..	19,380	8·65	16·85	0·0833	..	1,360·0	1·50	Fairly sound.
H_{13}	..	3·48	2·592	..	..	21,150	9·44	18·22	0·089	..	1,385·0	1·63	Sound.
H_{14}	..	3·34	2·595	..	..	16,440	7·34	14·13	0·0784	..	..	1·26	Sound.
K_{11}	..	3·14	2·381	0·026	4,760	13,560	6·05	12·72	0·0656	..	1,154·0	1·138	Bad blow-hole.
K_{12}	..	3·04	2·311	..	..	16,400	7·32	15·9	0·100	..	1,470·0	1·42	Quite sound.
K_{13}	..	3·14	2·373	..	..	13,010	5·81	12·2	0·0625	13,980,000	1,100·0	1·09	Not very sound.
K_{14}	..	3·00	2·330	..	..	14,600	6·55	14·05	0·0783	..	1,300·0	1·26	Sound.
L_{11}	Turned	2·89	0·693	0·0235	1,385	7,500	3·34	24·15	0·1459	14,720,000	454·0	2·185	Sound.
L_{12}	"	2·89	0·693	..	..	6,840	3·01	22·00	0·130	..	421·0	1·99	
L_{13}	"	2·89	0·693	..	..	8,310	3·71	26·70	0·175	..	511·1	2·414	Blow-hole on compression side.
M_{11}	..	2·98	0·727	0·0214	1,454	6,460	2·88	19·83	0·102	16,000,000	410·0	1·77	Blow-hole in centre.
M_{12}	..	3·14	0·784	..	..	7,410	3·31	21·13	0·125	12,100,000	449·0	1·89	Crystalline in centre.
M_{13}	..	3·079	0·761	..	..	7,410	3·31	21·70	0·111	..	449·0	1·94	
N_{11}	..	2·766	1·044	..	..	10,050	4·48	21·50	0·105	..	659·0	1·923	Sound.
N_{12}	..	2·823	1·082	0 0196	1,660	10,560	4·71	21·80	0·1135	14,860,000	681·0	1·95	Sound.
N_{13}	..	2·746	1·04	..	..	10,050	4·48	21·50	0·105	..	659·0	1·923	Cinder-flaw.
P_{11}	Turned	2·82	1·025	..	..	10,230	4·56	22·30	0·128	..	660·0	2·00	Sound.
P_{12}	"	2·73	1·007	0·022	1,512	8,730	3·89	19·36	0·109	14,100,000	572·0	1·75	Sound.
P_{13}	"	2·82	1·025	..	..	9,300	4·15	20·20	0·117	..	610·0	1·82	Sound.
R_{11}	..	..	1·03	0·019	1,686	8,850	3·95	19·1	0·0825	..	561·0	1·71	Sound.
R_{12}	..	..	1·056	..	..	9,000	4·01	19·1	0·0907	..	580·0	1·71	Sound.
R_{13}	..	..	1·093	..	..	8,910	3·98	18·20	0·0845	..	557·0	1·63	Sound.
R_{14}	..	..	1·093	0·019	1,686	8,920	3·98	18·20	0·079	14,800,000	557·0	1·628	Sound.
S_{11}	..	3·623	4·43	..	..	27,280	12·18	13·74	0·088	10,500,000	1,390·0	1·23	Unsound.
S_{12}	..	3·834	4·62	0·036	9,240	31,560	14·10	15·20	0·0866	8,590,000	1,540·0	1·36	Sound.
S_{13}	..	3·900	4·82	..	..	23,950	10·69	11·09	0·083	9,890,000	1,220·0	0·99	Large blow-hole in tension flange.
S_{14}	..	3·93	4·80	..	..	26,040	11·60	12·10	0·0928	..	1,270·0	1·082	Large blow-hole in tension flange.

GRAPHIC METHOD of DETERMINING the MOMENT of INTERNAL RESISTANCE of any CROSS-SECTION of a BEAM.

(See B. Baker "On the Strength of Beams, Columns, and Arches.")

Since one moment can only be completely balanced by another, the bending moments of the external forces acting on a beam can only be equilibrated by a moment of internal resistance. In the ordinary process of finding this internal resistance, only the tensile and the compressive couple are taken into account, other sources of resistance, such as shear, being practically of no consequence, and others such as values of principal stresses being very small and difficult to determine. From the fact that one side of a bent beam exhibits tension and the opposite side compression, it follows that there must exist one longitudinal section whose length remains unaltered during the process of bending. This section is known as the neutral plane. By Hooke's law the stress varies as the distance from the neutral plane; thus, considering a cross-section of a beam and a section of a very thin plane A B C D (Fig. 4), so that the stress may be assumed to remain constant over the area A B C D, the intensity of stress over A B C D will be equivalent to the intensity of stress in the extreme outer plane

FIG. 4.

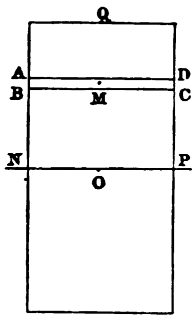
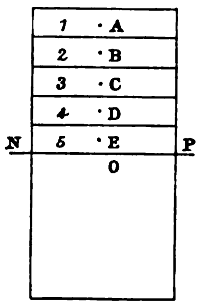


FIG. 5.



reduced in the ratio of the distance of A B C D from the neutral plane to the distance of the outer plane from N P; or

$$\text{Stress in A B C D} = \text{stress in outer plane} \times \frac{\text{O M}}{\text{O Q}}.$$

Consider now the whole section divided into sections of planes, which, for the moment, may be considered to have first an appreciable thickness, and let A B C D E (Fig. 5), be the mid points of these sections of the planes; also consider the planes to be so thin that the stress may be considered constant over the respective areas.

Let S = intensity of stress in the extreme outer rectangle.

Let n = area of extreme outer rectangle, then the stress in the—

1st rectangle . . . . $= n\,S$

2nd " . . . . . $= n\,S\,\dfrac{\text{B O}}{\text{A O}}$

3rd " . . . . . $= n\,S\,\dfrac{\text{C O}}{\text{A O}}$

4th " . . . . . $= n\,S\,\dfrac{\text{D O}}{\text{A O}}$

5th , ... $= n\,S\,\dfrac{\text{E O}}{\text{A O}}$

So the total stress in that section—

$$= n\,S + n\,S\,\frac{B\,O}{A\,O} + \&c.$$

$$= S\left(n + n\,\frac{B\,O}{A\,O} + n\,\frac{C\,O}{A\,O} + n\,\frac{D\,O}{A\,O} + n\,\frac{E\,O}{A\,O}\right).$$

The expression put in this form shows that instead of reducing the stress in the ratio of the distance of the rectangle from N P, the stress may be considered as constant, and the areas of these rectangles may be reduced in that ratio. If that be done a diagram is obtained such as the following shaded one (Fig. 6), where $A\,B = M\,K\,\frac{O\,C}{O\,D}$.

Now where the planes become infinitely thin the diagram becomes a triangle (Fig. 7), and if the area A B O is then multiplied by the intensity of stress in the extreme outer fibre, the total effective stressed area of that half of the section is obtained.

If the modulus of elasticity in tension be equal to the modulus in compression, the compressed portion of the section must contribute as much to the internal

FIG. 6.

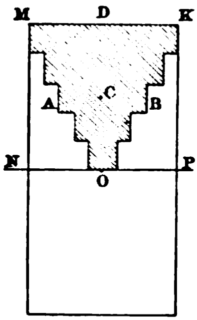
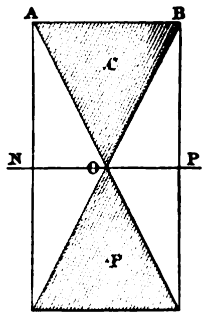


FIG. 7.



resistance as the extended portion; hence the effective stressed area on each side of the N P must be equal; hence the N P must pass through the centre of gravity of the whole section.

The resistance of the stressed areas may be considered as concentrated at the centre of gravity of this shaded area (called the equivalent figure); hence the area of either half of the equivalent figure multiplied by the distance between the centres of gravity of each half, and multiplied by the stress, constitutes the moment of internal resistance.

The quantity (area of half equivalent fig. × arm) is called Z. Thus A B O × C P = Z.

Let b = breadth of rectangular section = A B.
d = depth = B K,

then $A\,B\,O = \frac{b\,d}{4}$ and $C\,P = \frac{2}{3}\,d$,

hence $Z = A\,B\,O \times C\,P = \frac{2\,b\,d^2}{12} = \frac{b\,d^2}{6}$.

S Z being the moment of internal resistance must be equal and opposite to the

bending moment, in order that the beam may be in equilibrium under the load. Let M = bending moment;

then
$$M - S\,Z \text{ must} = 0.$$
$$M = S\,Z$$
$$S = \frac{M}{Z},$$

hence, knowing M and Z it is possible to calculate S, the stress in the outer fibre.

Now the moment of inertia of this section about N O P is $\frac{1}{12}\,b\,d^3$ which can be written $\frac{1}{6}\,b\,d^2 \times \frac{d}{2}$

$$= Z\,\frac{d}{2}.$$

So
$$M = S\,I\,\frac{d}{2}.$$

It can be shown that the equation $M = S\,I\,y$ holds for any section, y being the distance of the outer fibre of the half of the equivalent fig. considered from the neutral axis.

In symmetrical sections it does not matter whether the length of the outer fibre on the upper or lower side of the beam be taken to represent graphically the stress in that fibre: but in sections such as that of a tee-iron, the choice of the length of the fibre on the extended, or on the compressed side of the beam, materially alters the appearance of the equivalent figure, though not the value of the quantity Z. An explanation of this will be found in Mr. B. Baker's work "On the Strength of Beams, Columns, and Arches."

(*Paper No. 2145.*)

"On the Horizontal Range of Tidal Rivers, such as the River Orwell, with reference to Sewage Discharge."

By Charles Foote Gower, M. Inst. C.E.

The horizontal range of tidal-water in rivers is a term requiring some explanation as to the precise meaning intended to be conveyed. Speaking generally, it may be understood to refer to the distance that the tidal-water travels up and down a river. This definition, however, is not sufficiently explicit in dealing with the question of tidal-action, and its effects on sewage discharge.

The distance traversed by a tidal stream may be taken to mean that which, from a given point in the river, or from its point of junction with the sea, a floating body would go up, or come down, in the strength of the current on the flood- or the ebb-tide. A floating body, however, will travel a less distance near the side than in the centre of the channel; and, in different parts of the river, the space passed over will be found to vary with local peculiarities. It is necessary, therefore, to be precise in stating whether the distance travelled by a floating body at the centre or at the side of the channel is to be taken; or, whether the average distance traversed by all the particles of water, in a given cross-section of the river, is to be accepted as the meaning of the term horizontal range; and further, whether it is at the point of juncture with the sea, or at some point higher up the river, that the term is intended to apply.

Now the maximum or minimum distance, traversed by the particles of tidal-water in a river-channel, can only be arrived at by experiments, giving approximate and uncertain results; the mean or average distance, however, passed through by all the particles of water in a given cross-section of the tideway, can be ascertained with accuracy by computation, and is therefore that which commends itself to the Author as the proper interpretation of the term horizontal range, as applied to tidal rivers; the maximum and minimum being so much more or less than the mean horizontal range, as experiment may determine.

The horizontal range of the tide manifestly depends on the vertical range, that is, upon the quantity of tidal-water passing in,

or passing out to sea, with each flow and ebb. Thus if the vertical range be increased or diminished, the horizontal range will be affected in like manner. The horizontal range also depends, to a certain extent, upon the depth and capacity of the channel below low-water line.

In Fig. 1, the unshaded portion, C^2, shows the tidal-capacity of a river between high- and low-water line, 1,679,000,000 cubic feet,

Fig. 1.

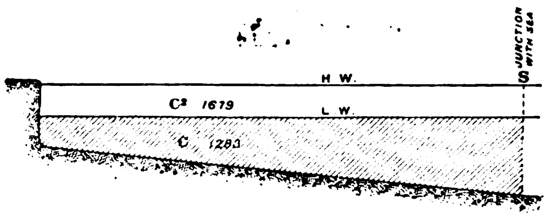


Fig. 2.

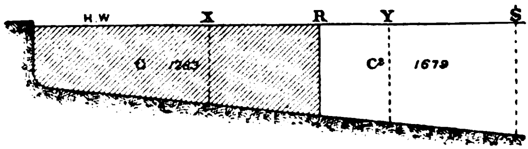
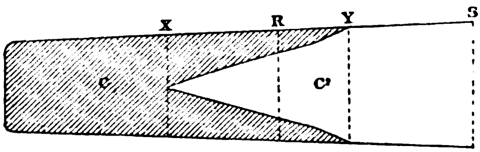


Fig. 3.



and the shaded portion, C, shows the capacity of the channel below low-water line, 1,283,000,000 cubic feet. On the tide coming in, the shaded part, C, will be pushed up, at high-water, to the position C, as shown in Fig. 2. R S is the measure of the horizontal range, R being the average distance to which the particles of tidal-water, in a given cross-section of the channel, will travel from S. The maximum distance that a floating body may be supposed to travel in the centre, and the minimum distance, near the side of the channel, is shown in plan at X and Y, Fig. 3, where the unshaded portion, C^2, represents the tidal-water penetrating like a wedge into the shaded part C, as it pushes it up to high-

water line, shown in Fig. 2. Between X and Y, a mixing of tidal- and river-water, it will be noticed, must of necessity take place; while all water below Y will be sea-water of full strength, and above X it will be entirely fresh. This at least will be the effect produced by a single tide.

In Fig. 4, the horizontal range at a point S^2, higher up than S, is shown; the unshaded part C^2 represents the tidal-capacity of a river above a point S^2, between high- and low-water line, 753,000,000 cubic feet; the shaded part C shows the capacity, above the same point, of the river-channel below low-water line, 313,000,000 cubic feet. In Fig. 5 are shown the respective positions of C^2, the unshaded, and C the shaded portion, at high-water, R S^2

Fig. 4.

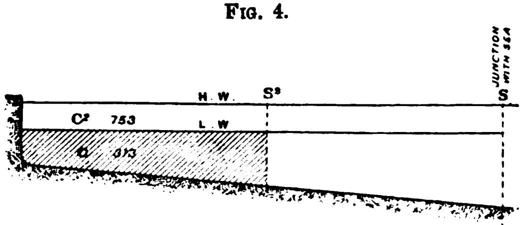
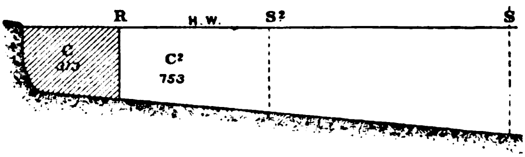


Fig. 5.



being the horizontal range; the latter, it will be observed, is less than R S in Fig. 2. This reduction of range becomes obviously more marked as the point S^2 is brought nearer to the head of the tidal column. The foregoing examples, it should be observed, are computed approximately from cross-sections of the Orwell, a river, the tidal portion of which has a somewhat abrupt termination near Ipswich, the upland stream coming into it being canalized, and comparatively of insignificant quantity. Where the tidal portion of a river comes to a less abrupt termination, a more equal length of horizontal range would prevail in all parts of the river.

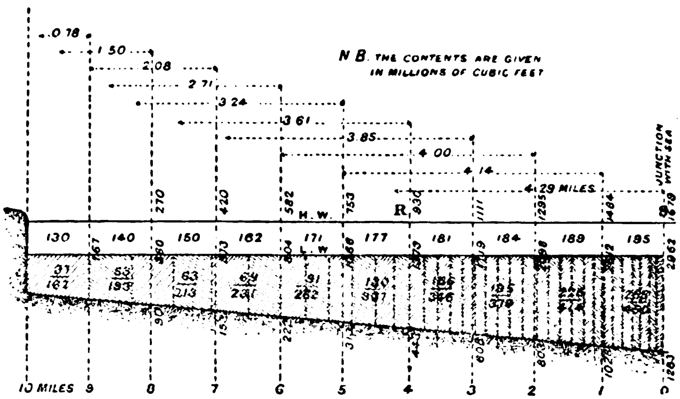
The horizontal ranges of the tide, at each mile from the sea upward, are shown in Fig. 6. The cubic contents, given between high- and low-water line, as well as below low-water line, cor-

respond approximately to those of the Orwell; and from these the horizontal ranges are computed in the following manner:—

Total tidal-water passing S, millions, cubic feet	1,679	
Space this will occupy between each cross-section 1 mile apart	450 = 1	mile
	414 = 1	"
	379 = 1	"
	346 = 1	"
	1,589 = 4	miles.
To make up total	90 = 0·29	"
Space due to 90 = 0·29	1,679 = 4·29	"

In working out the above computation, it will be noticed that the effect of upland-water has been disregarded, and consequently

Fig. 6.



the mean distance travelled by the tidal-water on the flood will be exactly equal to that on the ebb-tide, because the same volume of water that passes up on the flood, at any point, must also pass down on the ebb to the same low-water line. The horizontal ranges of the tide, as shown in Fig. 6 at each mile upwards from the sea, are all worked out as the foregoing example. It is hardly necessary to observe that they will be affected in various ways, by dredging and by other operations that enlarge or diminish the tidal-capacity of the river, or the depth and capacity of the channel below low-water line.

Some experiments tried by the Author, with a model trough, made to such a scale that 1 cubic inch corresponded to 10,000,000

cubic feet of the diagram, Fig. 6, showed, that floats went up in the centre of the trough from 30 to 60 per cent. greater distances than the computed horizontal ranges there given; that they travelled pretty nearly the same distance whether the tidal-water was admitted quickly or slowly; and, as was to be expected, that the length of tidal-range fell off towards the upper end of the trough. A float put in at S would go up nearly to the 7th mile, whether the tidal-water was admitted in sixty seconds or one hundred and twenty seconds—provided, of course, that the same volume of water passed up.

It will be seen from Fig. 6, that the space below low-water line, between the 9th and 10th mile, is equal to 37,000,000 cubic feet. Supposing, therefore, this quantity to represent upland-water, let in at the head of the river, it is obvious that it will occupy an equal space, and must cause an equal volume to flow into the next space below it, between the 8th and 9th mile, and so on till the sea is reached. The spaces shaded in opposite directions, below low-water line, in Fig. 6, thirty-five in number, are each equal to 37,000,000 cubic feet; and as the river widens and deepens, each succeeding space downwards represents a less distance passed through by the upland-water.

If, therefore, on each tide, 37,000,000 cubic feet be admitted at the head of the river, the water let in on the first tide will, at the thirty-fifth tide, be pushed just far enough down the channel to reach the sea at the period of low-water, while at high-water it will be pushed back by the flood-tide into the position shown by the shaded part C, Fig. 2, or, more correctly, by x and y in Fig. 3.

In this way, it will be understood, the river-water oscillates backwards and forwards with each flow and ebb, pushing out to sea 37,000,000 cubic feet at each pulsation. The effect of the upland-water upon the river, in this condition of things, is to raise slightly the low-water line, and thereby to diminish somewhat the horizontal range of the tide.

This action of the tide and of the upland-water is not, however, strictly in accordance with fact. It is true only on the assumption that no penetration or mixing takes place between the sea-water and the river-water, and that a vertical plane of demarcation is at all times maintained between them. If this assumption were correct, the tidal-water would simply act as a solid piston to push the water up and down in the river, at each pulsation, with the monotony of a machine; but this is not the case.

On admitting a small quantity of coloured water into the model trough, already mentioned, on the flood or ebb, it was noticed that

it penetrated into the uncoloured, or plain, water, in a long tongue, to a considerable distance in the centre of the trough, showing that sea-water may, in a similar manner, pass up into a river in the centre of the current, to a much greater distance than would otherwise be supposed; and also that the passage of land-water out to sea may be accelerated, in some measure, by being drawn into the central current of the outgoing tide. It was further observed, on filling the model trough with coloured water up to low-water line, corresponding with the shaded part of the diagram, Fig. 6, and admitting plain water in quantity to correspond with the unshaded part, that the uncoloured water from the sea (a box into which water was admitted or withdrawn by two taps), flowed up, in a long tongue or wedge form, in the centre of the trough, at the same time driving the coloured water forward to the head of the trough to high-water line, as shown in Figs. 2 and 3 by the shaded part C. On the ebb (when the water was withdrawn by the other tap) the opposite action took place, the coloured water penetrating downwards, in a tongue-like form, into the uncoloured water, a portion of the former passing out to sea (into the box) as it reached low-water line. On the experiment being repeated several times, it was noticed that the colour was gradually disappearing from the water in the trough, and that by the twenty-fifth tide it was hardly distinguishable. Judging from these experiments, about 4 per cent. of the coloured water was removed from the trough on each tide, its place being filled by uncoloured water; that is to say, river-water was exchanged for sea-water, at the rate of one twenty-fifth part with each tide. On admitting upland-water, uncoloured, at the head of the trough, it was found that the coloured water was accelerated in its passage seaward in proportion to the quantity admitted at the upper end.

The movements of floats, when placed in the centre of a tideway, have already been remarked upon. They pass up a certain distance with the flood-tide, and down again with the ebb, but make no advance seawards, except when assisted by the downward preponderance of land-water. The movements of substances that rest lightly on the bottom are similar to those of floating bodies at the surface, only much more restricted, the distances they travel upwards and downwards, by rolling or sliding, being but a small fraction of that which a float would pass over. Like floating bodies, these heavier substances seem to make no greater progress on the ebb- than on the flood-tide, and it is only by the aid of a considerable quantity of upland-water that they will travel towards the sea; their movements may,

however, be influenced a good deal by chance circumstances. Thus, when stirred by the passage of a steamer, or by other disturbance of the water, they will be carried along in whichever direction the stream may be running at the time, to be deposited again as the tide ceases.

With reference to the discharge of sewage into a tidal river, it is necessary to regard it as subdivided, roughly, into three distinct divisions. The first division consists of the floating débris, the most offensive part of sewage, which is carried upwards and downwards by the tide, and which, unless its downward movement is strongly influenced by flood-water, never leaves the river, but sooner or later is stranded, to decompose gradually upon the exposed mudbanks and foreshore.

The second division consists of the heavier mineral matter, mixed with some portion of putrescible filth, which sinks to the bottom, and is only moved slowly up and down to a comparatively short distance by the tide, until it finally becomes deposited, forming shoals of more or less offensive mud, in those places where the velocity of the current is not sufficient to keep it in motion.

The third division consists of the soluble portion of the sewage, which becomes mixed with the water into which it is discharged, and the action of which, in a tideway, is totally different from that of the floating débris, or of the heavier matter which sinks to the bottom. It acts in a similar manner to the coloured water referred to in the trough experiments, mixing with the incoming or outgoing tide; a portion of it is carried down with each ebb, and it would, after a time, but for the admission of fresh sewage, entirely disappear from the river.

To what extent the analogy between the above experiments, with a trough 10 feet long, and the action of a tidal river, of as many miles, in renovating itself by an interchange of fresh sea-water with every tide, may be borne out, it is not possible to say; but, that a certain amount of exchange between the sea- and the river-water does take place at each tide, there can be no doubt, even at a time when no upland-water is passing through. The salt-test adopted by Mr. R. W. P. Birch, M. Inst. C.E., for determining "the passage of Upland Water through a Tidal Estuary,"[1] might, perhaps, be of use in throwing more light on this point; but whatever the exact effect of tidal-action may be in removing the soluble part, forming the third division of the sewage, it has no effect in removing the floating substances, nor the heavier matter, forming the

[1] Minutes of Proceedings Inst. C.E. vol. lxxviii. p. 212.

first and second divisions, except when assisted by upland-water passing out to sea. In the absence of upland-water, these latter, the floating débris and that which sinks, remain in the river for an indefinite period, a source of nuisance and disgust.

In order, with reference to the discharge of sewage into a tidal river, to maintain the latter in such a condition as to be, at least, inoffensive to the senses, the Author is of opinion that all floating débris, mineral and putrescible matter, should be first separated from the sewage, by screening and deposition, before it is allowed to be discharged, and that where the quantity to be admitted into the river on any one tide exceeds, say, 1 per cent. of the tidal-volume at the point of discharge, it should also be clarified by land-filtration, chemical, or other appropriate treatment, as the circumstances of the case may require; and further that the point of discharge shall be such that the horizontal range of the tide shall not carry the sewage effluent upwards beyond a certain limit, to be defined in each particular instance.

The Paper is accompanied by several tracings, from which the Figs. in the text have been prepared.

(*Paper No. 2170.*)

"On the Practical Strength of Columns, and of Braced Struts."

By Thomas Claxton Fidler, M. Inst. C.E.

It is known experimentally that the strength of iron and of steel columns will sometimes be greatly affected by apparently minute changes in the conditions of the bar or of the experiment. This has been clearly illustrated by certain tests recently made in America, and particularly those recorded by Mr. James Christie,[1] which have shown that struts with hinged ends, fixed ends, and flat ends, will sometimes behave in a very unexpected manner, and that in practice their strength is influenced by causes which have commonly been regarded as of no appreciable importance.

It appears, therefore, that in making use of those well-known empirical formulas which have been constructed to represent the average results of experiments, an important question will arise, whether the actual conditions of the strut in the contemplated structure will be exactly the same as in the experiments relied on —and if not, what will be the effect of such variations as may be expected to take place in those conditions.

In addition to this uncertainty, it must also be remarked that some further information is needed as to the distribution of the direct and the shearing stresses in different parts of the column. Thus, in the case of the bridge recently proposed for crossing the St. Lawrence at Quebec, some of the compression members of the web-bracing were formed of four steel columns 180 feet in height, and united by cross-bracing; and in this case it was necessary to estimate by some process what shearing-stress should be provided for in the secondary bracing of these large struts.

The existing lack of information on these questions points to the necessity for further experiments, and also for further mathematical investigation; but, until these are forthcoming, practical men are obliged to make the best use of what they have, and it is

[1] Transactions of the American Society of Civil Engineers, 1884. April and September.

in this sense that the following observations are submitted as an endeavour to find a reasonable answer to some of these questions.

1. The theory of Euler proceeds upon the assumption of a purely ideal column, *i.e.*, a column consisting of a uniformly elastic material, or one in which the modulus of elasticity is the same for each longitudinal fibre, so that in the straight column the resultant line of the elastic resistances (or reactions) coincides with the axis of the column and with the line of pressure of the load; and if this hypothesis be true, the deductions of the theory in regard to the failure of long columns by transverse flexure must be correct.

2. These deductions, which are certainly at variance with the results of experiment, depend entirely upon the hypothesis above mentioned: and if the modulus of elasticity varies to a very small extent in different parts of the column, or if, in a braced strut, the modulus is slightly different in the different legs of the strut, it may be shown that the theoretical strength will be greatly reduced. Thus, for example, in a solid cylindrical column, the line of the elastic resultant may have an eccentricity equal to $\frac{1}{100}$ of the diameter, if the modulus is supposed to vary by 2 per cent. above and below its mean value; and the theoretical strength would then be reduced (in a column of certain proportions) by as much as 26 per cent. A greater variation of modulus does not appear to produce a proportionately greater reduction of strength; but if the variation of modulus and the eccentricity of elastic resistance are three times as great as above supposed, the strength of the column will be reduced by about 36 per cent.

3. The consequences of such a variation of modulus may be traced out by means of the graphic theory of deflection, recently described by the Author in a Paper on "Continuous Girder Bridges,[1] and its effect will be found to depend very greatly upon the ratio of length to diameter of column. In very long columns, or in very short ones, the effect of any inequality of modulus is almost imperceptible, but its greatest effect takes place in columns of the most usual proportions.

4. When the consequences of such a small variation of modulus are followed out, it appears that the theoretical deflection, unlike that of the ideal column, will be in accordance with experiment; while the observed breaking weight of columns of different materials and proportions will agree very well with theory, and will be consistent with the natural supposition that the ultimate

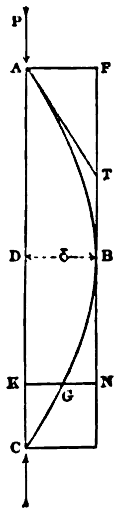
[1] Minutes of Proceedings Inst. C.E. vol. lxxiv. p. 196.

strength or ultimate stress in any given material depends only upon the material, and not on the shape of the column.

5. It will follow that the strength of a column depends, not wholly upon the ultimate strength of the material, nor wholly upon its modulus of elasticity, as implied by Euler's theory, but upon both these quantities taken together, and also upon the extent of local variations of modulus.

The Ideal Column.—When a column with rounded ends is bent to a moderate deflection under the action of a vertical load P, as shown in Fig. 1, the conditions which govern the equilibrium of the opposed forces, may be found by the ordinary laws of elastic deflection, and thus the value of the equilibrated load P may be determined. The action of the load might in fact be replaced by the tension of a string AC, and the load P can be neither more nor less than the tension which would be exerted upon the string by the resilient force (R) of the bow, acting in the line AC. It may readily be shown, by the graphic theorem of deflection, that the force R, or tension of the string, is practically a constant quantity independent of the extent of deflection.[1]

FIG. 1.



Let the curve ABC represent the axis of the column (originally straight); then the bending moment at any point, G, will be equal to the ordinate GK multiplied by the force R, or by the equilibrated load. The curve ABC may therefore be regarded as a diagram of bending moments; and the peculiar feature of the bent column is that the curve of deflection and the curve of moments must be identical. The ordinate $BD = \delta$ is not only a measure of the deflection, but also of the bending moments producing that deflection.

The graphic theorem, above referred to, shows that in any beam of uniform section, the curve of deflection may be constructed from the diagram of moments, in the same way that the curve of moments is constructed from a diagram of the distributed load; that is to say, the slope of the beam will be proportional to the

[1] This may not perhaps be accurately true if the column is regarded as a perfectly elastic spring, which is capable of being bent double or tied in a knot without impairing its elasticity; but it is practically true for the deflection of ordinary columns within the elastic limit.

area of the diagram of moments, and the deflection will be proportional to the moment of that area.

It follows, therefore, that the curve of the bent column must have the following properties, viz., if a tangent F B N be drawn (parallel to the chord A C), the inclination of the curve at any point G, must be proportional to the area B D G K, while the deflection N G must be proportional to the moment of that area about G K as an axis. By the same rule the inclination of the tangent A T must be proportional to the area A B D, and the deflection F A = B D = δ must be proportional to the moment of that area about the point A, while the sub-tangent F T must consequently represent the vertical distance from A to the centre of gravity of the area A B D. These equations indicate that the required curve is the "curve of sines" whose properties are given for reference in the Appendix. But without examining the precise nature of the curve, it is evident that if the length A C is regarded as being sensibly constant, the area of the diagram and its moment about A will be simply proportional to the central ordinate B D = δ, representing the maximum bending moment $R\,\delta$. But δ is also the elastic deflection, and therefore $\delta \propto R\,\delta$, which shows at once that R is a constant quantity independent of the deflection.

The exact value of R is readily found by measurement of the curve, and it is shown in the Appendix that if l denotes the length of the chord A C, the length of the subtangent F T will be $k = \frac{l}{\pi}$; while the area of the half segment A B D will be equal to $\frac{l\,\delta}{\pi}$. Therefore at the point A, the moment of the diagram of bending moments will be $R\,\delta \frac{l^2}{\pi^2}$; and the elastic deflection B D will be expressed by $\delta = \frac{R\,\delta}{E\,I} \cdot \frac{l^2}{\pi^2}$, in which I is the moment of inertia. It follows, therefore, that the equilibrated load, or the resilient force R, will be

$$R = E\,I \cdot \frac{\pi^2}{l^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Dividing by the sectional area of the column, the resilient force (or tension of the string) may be expressed in lbs. per square inch of the column's section, by

$$\rho = \frac{R}{\text{area}} = \pi^2\,E \cdot \frac{r^2}{l^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

in which r denotes the radius of gyration. These expressions are

in accordance with Euler's theory; and the following propositions may be deduced in regard to the behaviour of the ideal column.

1st. Using P to denote any arbitrary load, it will follow that so long as the load P is less than R, there will be no deflection of the column whatever; and if such a deflection is forcibly produced by applying a lateral pressure at the centre, the bow will always straighten itself again as soon as the pressure is removed, and will lift the incumbent load by reason of the excess of R over P.

2nd. If the load P is now increased until it is exactly equal to R, the behaviour of the column will be different; the load itself will not produce any deflection, but the smallest conceivable force applied laterally at the centre will be sufficient to bend it to any required extent; and if the column is so bent and the lateral pressure removed, it will not now recover itself as heretofore, neither will it yield any further, but it will remain supporting the load in any bent position in which it may be placed. In fact, the column will be in a condition of indifferent equilibrium,[1] and will carry the load just as well in one position as in another.

These deductions may easily be verified by experiment, if only sufficient care is taken to conform to the conditions of an ideal column by first straightening or rather adjusting the bar so that the line of resistance coincides exactly with the line of pressure; but unless this is done the bar will not behave in the manner described, even though it may appear to be perfectly straight and accurately centred.

3rd. If the load P is now increased by the smallest amount, the excess of P over R will place the column at once in a condition of unstable equilibrium, and it will either be broken or bent double; and therefore the resilient force R is the measure of the breaking load. It follows, of course, that the strength of a long (ideal) column is independent of the ultimate strength of the material, and depends only upon the modulus of elasticity E. Thus a long column of the strongest steel would be little or no stronger than a similar column of wrought iron, because the modulus of elasticity is nearly the same in both materials; and however great the ultimate resistance of the steel may be, the crushing stress will inevitably be reached at some period of the increasing bending strain, if only the load is sufficient to overcome the resilient force of the bow, and to set up the ever-increasing deflection.

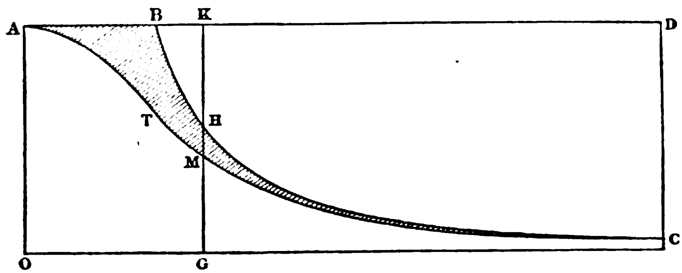
[1] It may be remarked that when the deflection is carried so far as to sensibly shorten the chord A C, the column passes into a condition of unstable equilibrium, because practically the limit of elasticity will then be exceeded.

The only difference that may be theoretically expected between the two is that the steel column would take a greater ultimate deflection than the wrought-iron column, before it became actually crushed or crippled on the concave side; but the breaking weight would be the same for both.

4th. If, however, the column is a very short one, or if the ratio of length to radius of gyration is less than a certain quantity, the column will not be bent at all, as the load required to bend it would be greater than the load which would crush it. Within these limits the strength of the column would of course be determined by the ultimate strength of the material.

These theoretical results for the ideal column may be illustrated by a diagram, such as A B C, Fig. 2. In this Fig., as in all the

Fig. 2.



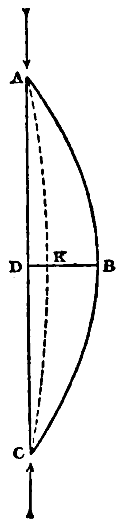
following diagrams, the abscissæ represent the values of the ratio $\frac{l}{r}$, while the ordinates give the corresponding values of the breaking-weight in lbs. per square inch. The curve B C denotes the value of the resilient force $\rho = \pi^2 E \frac{r^2}{l^2}$, and is intersected at B by the straight line A B D, representing the constant value of f, or the ultimate crushing strength. If it is assumed that the crushing-stress will always have the same value (on the concave side), then G H denotes the stress due to the direct load, and H K the stress due to the ultimate deflection or ultimate bending moment.

The Practical Deflection of Columns.—The ultimate strength of a column must certainly depend in large measure upon its deflection; but, according to the propositions just stated, there is no assignable value for the elastic deflection of a column under any given load. If the load P is less than the constant quantity R, there is no deflection at all; and if the load is equal to or greater than R, the deflection has practically no limits.

These propositions, however, will only hold good so long as the conditions are precisely those which are assumed in the ideal column. In practice these conditions will seldom or never be perfectly complied with; and if they are departed from to the smallest extent, the deflection will take place according to a different law.

As a simple illustration, let it be supposed that the neutral axis of the unstrained column is not exactly a straight line, but slightly curved, as shown by the dotted line A K C, Fig. 3. Such a curvature may either be regarded as an initial deflection, or as permanent set, which may have been developed unseen during the course of an experiment, and which would entail the same consequences as though it had been noted at the beginning of the experiment. In this case it may be assumed that the curve of permanent set A K C, like the curve A B C, will be nearly proportional to the ordinates of the curve of sines.

Fig. 3.



Then the *elastic* deflection of the column at any point will be represented by the space between the two curves; but the diagram of moments will be the whole segmental area A B C D. These two geometrical areas will therefore not coincide with each other as in the ideal column; but applying the same geometrical theorem, the elastic deflection B K must be proportional to the moment of the half segmental area A B D; and the equilibrated load P will be less than the value R (as previously determined) in the proportion of B K to B D.

Let R denote the resilient force of the ideal column, equal to $E\, I \frac{\pi^2}{l^2}$; and let ϵ denote the initial deflection D K, and δ the elastic deflection B K.

Then $$P = R \cdot \frac{\delta}{\delta + \epsilon} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

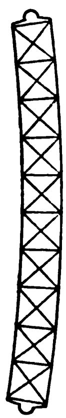
and $$\delta = \epsilon \cdot \frac{P}{R - P} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Therefore the deflection will now have a certain assignable value depending on the load; and if the load P is gradually increased, the column will exhibit an increasing deflection for each increasing value of the load. Within the elastic limit the column will always

be in stable equilibrium; and it is evident that when the load P approaches to the value of R, a very small initial curvature will be sufficient to produce a very large deflection of the column. It is not necessary, however, to assume the existence of any initial curvature. Experiment has shown that test-pieces, even when cut from different parts of the same bar, will sometimes exhibit considerable differences in the modulus of elasticity; and it may be shown that the deflection of the column will follow a similar law if the modulus is somewhat greater on one side than on the other.

The effect of such an inequality of modulus is most easily seen in the case of a strut, consisting of two flanges (or legs) braced together as a girder, Fig. 4. The flanges will be of equal sectional area, and the radius of gyration will be equal to half the depth of the girder.

FIG. 4.



Let e_1 = the specific compression of inner flange $= \frac{1}{E_1}$.

e_2 = do. do. of outer flange $= \frac{1}{E_2}$.

Then it is shown in the Appendix that the central deflection will be

$$\delta = \frac{\pi r}{2} \cdot \frac{e_1 - e_2}{e_1 + e_2} \cdot \frac{P}{R - P} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If the two flanges were shortened by the same amount under compressive stress, their resistances would be respectively as E_1 to E_2, and the resultant line of resistance would be moved from the axis of the strut by the eccentricity $r \cdot \frac{e_1 - e_2}{e_1 + e_2}$. Therefore equations (4) and (3) show that the deflection of the strut is the same as if it had an initial deflection ϵ equivalent to the eccentricity of the resultant multiplied by $\frac{\pi}{2}$.

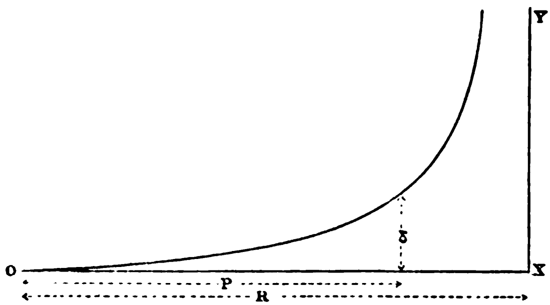
Or again, the analogy between the two cases may be stated in another form. If the two flanges are to exert the same compressive stress, one flange must be shortened more than the other in the proportion of e_1 to e_2; and this will happen when the column is curved to the dotted line A K C, Fig. 3. So that the moment of the elastic resisting stresses, and the equilibrated load, will only be proportional to the residual deflection B K.

It appears, therefore, that the deflection of a column under an

increasing load will be expressed by the formula $\delta = c \cdot \frac{P}{R - P}$, in which c is a constant depending on inaccuracy of form or of centreing, and if neither of these exists, depending on the inequality of modulus.

The curve, Fig. 5, having δ and P for its co-ordinates, illustrates the general law according to which the deflection should increase with the load; and it may be remarked that this curve appears to correspond very nearly with the results of experiment, although in each individual case the vertical scale will vary according to the value of c, which may naturally be expected to show a considerable variation in different bars. In the ideal column, $c = 0$, and the diagram then consists of the two straight lines O X and X Y; but such a case is hardly ever recorded in practice; on the contrary, the experiments of Mr. Hodgkinson, Mr. Christie, and

FIG. 5.



other observers, are almost always accompanied by a table of observed deflections, increasing with the load in the manner shown by the curve of the diagram;[1] and this fact is sufficient to demonstrate that a certain eccentricity, or inequality of modulus, is always present and governs the deflection of the column in the manner above described.

The Practical Strength of Columns.—In formula (4), putting $\phi = \frac{\pi}{2} \cdot \frac{e_1 - e_2}{e_1 + e_2}$, and expressing P and R in lbs. per square inch of sectional area, by p and ρ, the central deflection of the

[1] The recent experiments of Mr. Christie have shown that by feeling for the line of elastic resistance, and applying the load accordingly in a somewhat eccentric position, the resistance of the column may be considerably increased, and its behaviour will then approximate to that of the ideal column.

braced strut will be $\delta = \phi r \cdot \frac{p}{\rho - p}$; the intensity of flange-stress due to the bending moment $P\,\delta$ will therefore be $\pm f_1 = \frac{\phi p^2}{\rho - p}$; and the maximum intensity of compressive-stress on the inner flange due to the load and to the bending moment will be

$$f = p + f_1 = p\left(1 + \frac{\phi p}{\rho - p}\right) \quad . \quad . \quad . \quad . \quad (5)$$

This expression represents the relation between the apparent stress p and the greatest actual compressive-stress f in the concave flange of the girder-shaped strut; and if f is now taken to denote the crushing-stress of the material, it will follow (by reduction) that the breaking-weight of the column in lbs. per square inch will be expressed by

$$p = \frac{f + \rho - \sqrt{(f+\rho)^2 - 4 f \rho (1 - \phi)}}{2(1 - \phi)} \quad . \quad . \quad (6)$$

According to this formula, the strength of columns will be represented by a wave-line curve, such as the curve A T C, Fig. 2, or any of the curves A C in the several large diagrams. At A the curve touches the straight line A B, and at C it approaches indefinitely near to the curve of the ideal column; so that if the column is very short or very long, the practical strength is equal to the theoretical strength of the ideal column. But with intermediate values of the ratio $\frac{l}{r}$, the presence of any eccentricity or inequality of modulus produces a marked reduction in the theoretical strength, the reduction being greatest at the point B in the diagram, where $f = \rho$, and where

$$p = f\frac{1 - \sqrt{\phi}}{1 - \phi} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

The curve A T C, Fig. 2, may be understood as representing the strength of struts, on the supposition that the difference between the modulus of elasticity in the two flanges is equal to the greatest difference commonly observed in the modulus of the given material. If the inequality of modulus is less than this, the curve A T C will approach nearer to the curve of the ideal column, and will coincide with the line A B C if ϕ is taken as nothing. It will be seen, therefore, that the strength of columns *cannot be defined by any hard and fast line*, even when the modulus for the whole column and the ultimate strength of the

material are accurately known; but on the contrary, the strength may have any value less than that of the ideal column within certain limits. The strength of columns must, therefore, be represented by *an area*, as shown in Fig. 2, within which the results of individual experiments may be expected to place themselves at hap-hazard. The upper limit will be the line of the ideal column A B C, and it remains to determine for each material the position of the lower limit A T C, which must evidently be regarded as the greatest reliable strength of the column.

Wrought-iron columns.—The average value of the modulus of elasticity in wrought-iron is about 26,000,000 lbs.; and, therefore, $\rho = 26{,}000{,}000\, \pi^2 \cdot \frac{r^2}{l^2}$. But the modulus is known to vary commonly between 23 and 29 millions, and occasionally the range is somewhat greater. Adopting these figures for the greatest probable inequality, the fraction $\frac{e_1 - e_2}{e_1 + e_2} = 0 \cdot 117$; so that the greatest probable eccentricity of elastic reaction will be about $\frac{1}{8}$th of the radius of gyration. Thus, in a solid cylindrical column 1 inch in diameter, the eccentricity would be about $\frac{1}{32}$th of an inch.

It is shown in the Appendix, that for columns of any section, the maximum compressive-stress on the extreme fibre, due to the bending moment, will be expressed by the formula $f_1 = \frac{\phi\, p^2}{\rho - p}$, if ϕ is taken to represent the value $\frac{y}{r} \cdot \frac{\pi}{2} \cdot \frac{e_1 - e_2}{e_1 + e_2}$, in which y is the distance of the extreme fibre from the neutral axis. Therefore, the breaking-weight of any column may be expressed by formula (6), if ϕ is understood to have that value in every case; but it is unfortunate that the case of wrought-iron can only be examined upon somewhat arbitrary assumptions.

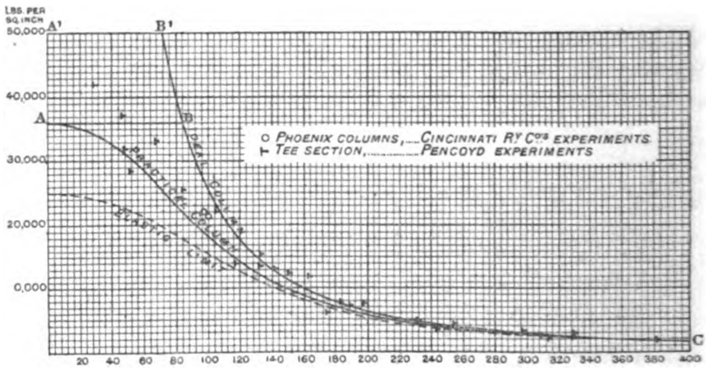
The ultimate strength of wrought-iron in compression, or the stress which causes failure in short specimens by bulging or crippling, may provisionally be taken as varying from 36,000 to 50,000 lbs.;[1] and as the object is to define the lower limit in the strength of columns, the lower of these values of f will be first taken, and the results of formula (6) may then be compared with actual experiment.

The most complete series of experiments on wrought-iron and steel struts, known to the Author, are those recently made by

[1] See concluding observations.

Mr. J. Christie,[1] at the Pencoyd Ironworks, Pennsylvania. In these experiments, the round-ended struts were chiefly of T-section,

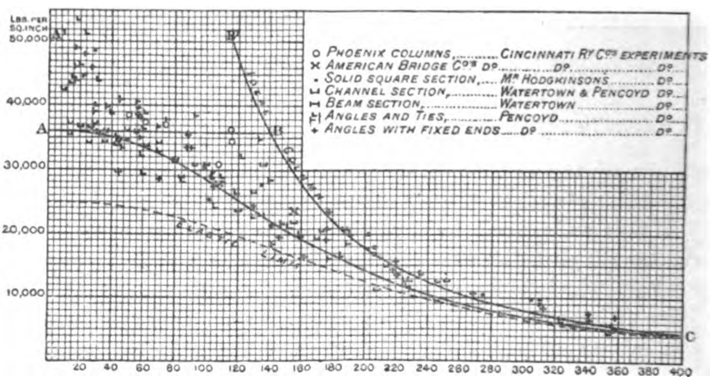
Fig. 6.



Ratio of Length to Radius of Gyration.

Wrought-Iron Columns. Round Ends.

Fig. 7.



Ratio of Length to Radius of Gyration.

Wrought-Iron Columns. Fixed Ends.

and the factor $\frac{y}{r}$ was in general about 2·2, so that the greatest

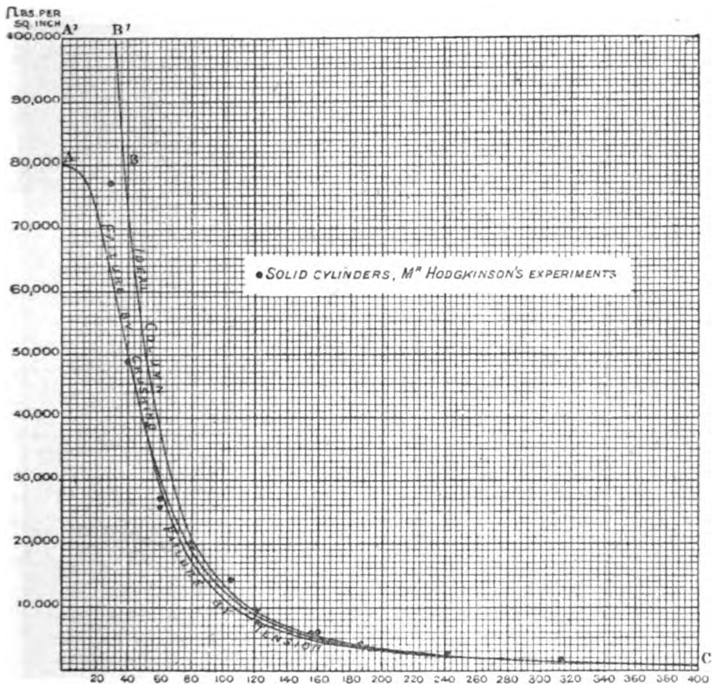
[1] Transactions of the American Society of Civil Engineers, 1884. April to September.

probable value of ϕ is 0·4 nearly, and the breaking-weight will then be—

$$p = \frac{f + \rho - \sqrt{(f + \rho)^2 - 2 \cdot 4 f \rho}}{1 \cdot 2} \quad . \quad . \quad . \quad . \quad (6b)$$

This lower limit of the theoretical strength is shown in the diagram, Fig. 6, by the wave-line curve A C; while the upper limit, or curve for the ideal column, is described by the line A B C.

FIG. 8.



Ratio of Length to Radius of Gyration.

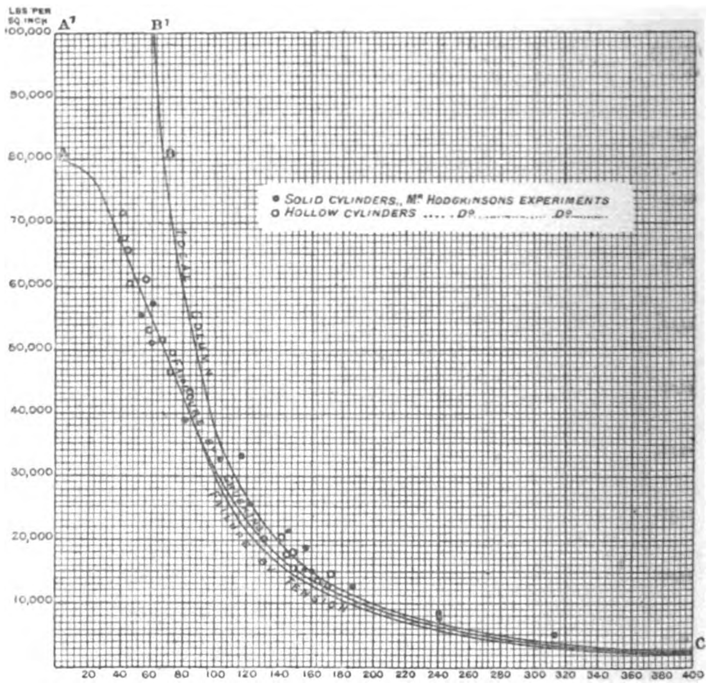
CAST-IRON COLUMNS. ROUND ENDS.

The actual values of the individual experiments are given by the constellation of tees, which spread themselves over the area, and in a few instances, lie somewhat beyond the limits, but adjacent to them. The lower limit applies, of course, to iron with an ultimate strength of 36,000 lbs.; and in order to extend the diagram for any greater strength of material up to 50,000 lbs. it

is only necessary to continue the ideal curve C B until it intersects the straight line A_1 B_1 drawn at 50,000 lbs.; for it has already been shown that the greatest strength of the column will not be increased in the slightest degree by the increased strength of material, except in the small area $A_1 B_1$ A B.

The entire envelope A_1 B_1 C A, should therefore include the results for every strength of material between 36,000 and

FIG. 9.



Ratio of Length to Radius of Gyration.

CAST-IRON COLUMNS. FIXED ENDS.

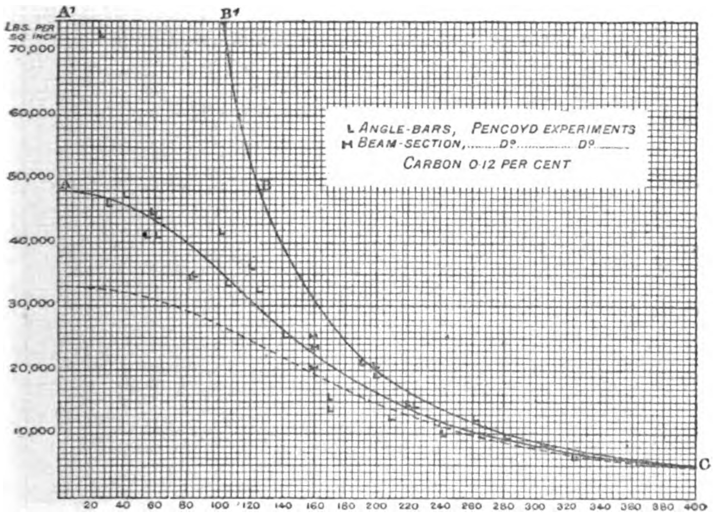
50,000 lbs., and it will be seen that practically it forms very nearly the boundary of the actual results of experiment.[1]

The Author would submit that if this formula expresses approximately the real physical conditions which govern the deflection and

[1] The abnormal exceptions lying just outside the boundary may of course be readily accounted for, if in these cases the average modulus is a little higher or lower than 26,000,000 lbs.

bending-stress of columns, it must be applicable to columns of other materials when the proper coefficients are introduced. The several diagrams, Figs. 6, 7, 8, 9, 10, and 11, represent the theoretic limits, and also the results of experiment in columns of wrought-iron, cast-iron, and of mild and hard steel; and it will be seen that in every case the theory coincides as closely with experiment as could be expected, if some allowance is made for the widely varying strength of the material known as mild steel. Further reference will be made to these diagrams; but it may be noted that in Fig. 7, which contains a great number of experiments, the recorded results are crowded pretty closely about the lower limit,

FIG. 10.



Ratio of Length to Radius of Gyration.

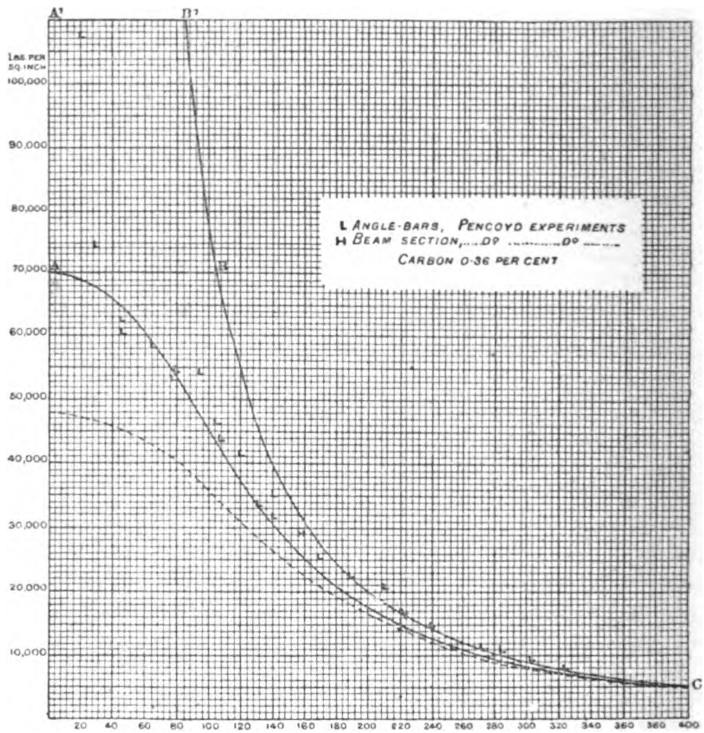
COLUMNS OF MILD STEEL. FIXED ENDS.

and only a few come near to the strength of the ideal column. This is what might be expected, for it may be shown that a moderate decrease in the assumed value of ϕ, will only raise the line AC by a very small amount; and for this reason the same value of ϕ has been adopted as the limit for columns of any section.[1]

[1] With the same inequality of modulus, the value of ϕ for the different sections will range between 0·4 for T bars, and 0·3 for Phœnix columns. If the latter value is taken for Phœnix columns, the two cases represented in Fig. 6 will be found to lie very close to the altered theoretical limit.

Columns with fixed ends.—When the ends of the column are fixed, it is commonly assumed that the points of contrary flexure A and C, in Fig. 12, will occur at one-fourth and three-fourths of the total length FG, so that the curve AB is similar to the curve AF, and the effective length of the bow AC is equal to half the total length. But this assumption again is only true in

Fig. 11.



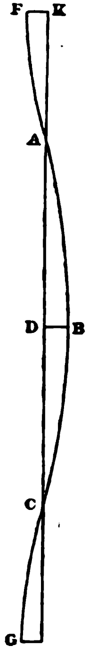
Ratio of Length to Radius of Gyration.

Columns of Hard Steel. Fixed Ends.

the case of the ideal column. If the average modulus of elasticity E_1 for the bow AC is greater than the average modulus E_2 for the ends AF and CG, it will follow by the geometric theorem, that the area ABD will be to the area AFK as E_2 is to E_1, because the slope at A is common to both curves. But again, if the inequality of modulus takes place in the other direction, *i.e.* if the modulus in one flange of the strut is through-

out greater than in the other flange, it will follow that the area A B D must be greater than the area A F K (or *vice versâ*) by a constant quantity. In the latter case, the reduction of strength in short columns would be relatively greater than in long columns; and a very short column with fixed ends would be theoretically less strong than a similar column with round ends.[1] For practical purposes, however, the limiting effect of these contingencies, as well as that of imperfect fixity of the ends, may roughly be covered by taking the effective length of the bow AC, as equal to six-tenths of the total length FG; and the diagrams for the theoretical limits of fixed-ended columns are accordingly constructed as parallel projections of the curves for round-ended columns.

Fig. 12.



Cast-iron Columns.—The average value of the modulus of elasticity in cast-iron, is about 14,000,000 lbs., and therefore for the ideal cast-iron column, $\rho = 14{,}000{,}000\ \pi^2 \frac{r^2}{l^2}$; while the variation, commonly observed in the modulus of different specimens, bears nearly the same proportion to the average modulus as it does in wrought-iron and in steel. Therefore, in all these materials, ϕ will have the same value, and the general formula (6 *b*) will represent in all cases the value of the load or apparent stress which produces the ultimate crushing-stress f on the concave side of the column. In good cast-iron, the crushing-stress will range from 80,000 to 100,000 lbs., or somewhat higher; and taking the lower value as before, the curve AC in Figs. 8 and 9 describes the lower theoretical limit for columns with round ends and fixed ends respectively. But owing to the comparative weakness of cast-iron under tensile stress, the column may be expected to give way by tension on the convex side if the length exceeds a certain ratio. For the stress on the extreme fibre will be expressed by—

$$f = p\left(1 - \frac{\phi\, p}{\rho - p}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

which will be either compression or tension, according as it has a positive or a negative value; and putting f_t = the ultimate tensile

[1] Mr. Christie finds this to be an experimental fact in the case of the L bars tested by him.

stress, it will follow that the apparent stress p_1, which is capable of destroying the column by tension, will be given by—

$$p_1 = \frac{\rho - f_t + \sqrt{(\rho - f_t)^2 + 4 f_t \rho (1 + \phi)}}{2(1 + \phi)} \quad . \quad . \quad (8)$$

The tensile strength of cast-iron may be taken at 14,000 lbs.;[1] and the resulting values of the breaking load are represented by the lower curve in Figs. 8 and 9, marked "Failure by Tension." It appears, therefore, from the diagrams, that the column may be theoretically expected to give way by tension on the convex side if the ratio of length to radius of gyration is greater than 50 in round-ended columns, or than 83 in columns with fixed ends. The results of Mr. Hodgkinson's experiments with solid and with hollow cylindrical columns are given in the diagrams, and coincide practically with the theoretical limits at all proportions of length to diameter; so that there appears to be no necessity for separate formulas applicable to certain lengths.

Steel Columns.—According to some experiments the modulus of elasticity in steel is no greater than in wrought-iron, but on the average it may probably be credited with a somewhat higher modulus, which will be taken at 29,000,000 lbs. The strength of the ideal column, or $\rho = 29{,}000{,}000\ \pi^2 \cdot \frac{r^2}{l^2}$, will therefore be only slightly greater than in wrought-iron.

The ultimate strength of steel, whether in tension or compression, is known to vary within very wide limits; but, as before stated, this will not in any way affect the curve B C forming the upper limit of Figs. 10 and 11. It is necessary, however, to fix some value of f for the probable lower limit.[2] Mr. Kirkaldy finds that the ratio of tensile to compressive strength in steel is the same as in wrought-iron; and therefore if f is taken at 70,000 lbs. for hard steel, it will correspond with a tensile strength of about 40 tons. With this value of f, the lower limit for columns of hard steel with fixed ends will be described by the wave-line curve A C in Fig. 11; and the same limit for columns of mild steel will be defined by the curve A C, Fig. 10, supposing f to have a value of 48,000 lbs. But it must be remarked that the

[1] This value, however, is derived from experiments in direct tension. Perhaps it would be more correct to take the much higher value given by experiments on cross-breaking. In this case, the curve of "failure by tension" would lie still nearer to the curve of "failure by crushing."

[2] See concluding observations.

material known as mild steel may have any strength between 25 and 36 tons. The experiments shown in the diagrams are those of Mr. Christie, made with bars of L and I section, in which the percentage of carbon averaged 0·36 in the hard steel, and 0·12 in the mild steel.

Practical Breaking Weight of Columns.—As nothing can be predicted with certainty in regard to the actual variation of modulus, and as no allowance has been made in the assumed value of ϕ for any imperfection of workmanship, the lower limit in each diagram must be taken as the only measure of strength that can safely be relied on; and the following Tables will then give the strength for each material as calculated by the formulas above given, and for ordinary proportions of length to diameter these values will be found to agree very closely with the Tables containing the results deduced from experiment by Mr. Christie and others.

Table I.—Strength of Columns with Round Ends, in lbs. per Square Inch of Sectional Area.

Ratio $\frac{l}{r}$.	Cast-Iron.	Wrought-Iron.	Mild Steel.	Hard Steel.
20	72,300	35,200	46,700	67,200
40	50,800	32,600	42,700	58,600
60	30,000	28,400	36,000	45,500
80	17,600	23,200	28,300	33,000
100	11,700	18,200	21,500	23,700
120	8,300	14,100	16,400	17,500
140	6,300	11,100	12,700	13,300
160	4,900	8,800	10,100	10,400
180	3,900	7,200	8,160	8,360
200	3,200	5,900	6,710	6,850
220	2,680	4,970	5,620	5,710
240	2,270	4,210	4,750	4,820
260	1,950	3,640	4,080	4,130
280	1,690	3,140	3,550	3,570
300	1,480	2,750	3,100	3,130
320	1,300	2,430	2,730	2,740
340	1,160	2,160	2,430	2,440
360	1,040	1,940	2,190	2,190
380	940	1,730	1,960	1,960
400	850	1,570	1,760	1,760

TABLE II.—STRENGTH of COLUMNS with FIXED ENDS, in lbs. per SQUARE INCH of SECTIONAL AREA.

Ratio $\frac{l}{r}$.	Cast-Iron.	Wrought-Iron.	Mild Steel.	Hard Steel.
20	77,600	35,800	47,400	68,700
40	67,800	34,900	45,700	65,800
60	54,700	33,400	43,800	60,500
80	42,000	31,100	39,900	53,600
100	30,000	28,400	36,000	45,500
120	21,200	25,300	31,000	37,400
140	16,000	22,200	26,500	30,500
160	12,600	19,200	22,500	25,000
180	10,200	16,500	19,100	20,900
200	8,300	14,100	16,400	17,500
220	6,900	12,100	13,900	14,900
240	5,700	10,500	12,000	12,600
260	5,000	9,300	10,400	11,000
280	4,400	8,200	9,100	9,500
300	3,900	7,200	8,200	8,400
320	3,400	6,300	7,200	7,300
340	3,000	5,600	6,300	6,500
360	2,700	5,100	5,500	5,700
380	2,470	4,600	5,100	5,200
400	2,270	4,210	4,750	4,800

These calculations merely exhibit the consequences that follow from a certain assumption; viz., that the modulus is subject to local variation within the stated limits; and the result of this assumption (which is certainly more reasonable than the contrary one), has been shown to agree very well with experiment, not only in regard to deflection, but also in regard to the breaking weight of columns of all proportions and in each material.

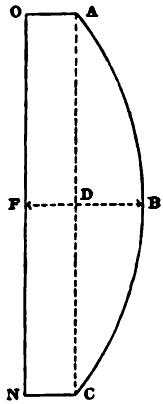
If the theory is correct in principle, it may perhaps be usefully employed to elucidate the following points on which experiments are still wanting.

Braced Struts and Piers.—If the girder-shaped strut, Fig. 4, were intended to be used as a girder, it would not be considered sufficient to calculate only its maximum section by a single formula, but each member would be proportioned to the greatest stress it has to bear.

In Fig. 2, let O G represent the ratio $\frac{l}{r}$ in any braced strut with round ends. Then, if the strut is loaded with the breaking-weight, the ordinate G M will represent the flange-stress due to the direct load, and M K will represent the flange-stress at the centre

of the girder due to the bending moment. It appears, therefore, that theoretically the sectional area of flange may be reduced at the ends in the proportion of G M to G K, as shown in the diagram of flange-stress Fig. 13, in which the ordinates of the curve of sines A B C represent stress due to bending moment, while the rectangle A O N C represents the constant stress due to the direct load. This diagram would apply to the case of greatest variation of modulus if B D is made proportional M K, Fig. 2; while in the case of an ideal column with no variation of modulus, it would only be necessary to make B D proportional to H K. It appears, however, that each flange of the braced strut must itself be considered as a column having points of contrary flexure at each intersection of the bracing. Thus each bay of the flange would first be considered as a round-ended column having its own small moment of inertia; and its individual breaking-weight having been found (in lbs. per square inch), this value would be substituted in place of f in the general formula for the strength of the entire strut.

Fig. 13.



With regard to the diagonal bracing, it is evident that the theoretic shearing-stress may easily be computed from the diagram of flange-stress, Fig. 13. When the ratio $\frac{l}{r}$ is indefinitely great, the distribution of stress in the flanges and web approximates very nearly to that which occurs in a girder uniformly loaded and supported at each end. But with moderate proportions of length to breadth, the theoretic shearing-stress is relatively small, and in many cases will form but a small fraction of the stress in the diagonals due to other and quite different causes. Thus it is well known that in certain arrangements of bracing, the diagonals will partake in the general compression of the entire column, and the stress due to this cause may be separately computed. Again, in the case of the braced piers of a viaduct, which are fixed at the base and practically free at the top, the effective length of the bow A C will of course be twice the height of the pier, and the small shearing-stress due to the vertical load may be computed; but this will be quite distinct from the greater shearing-stress due to horizontal wind-pressure; and the same remark will apply to any strut which is intended to act as a stiffener of the general structure in either a longitudinal or a transverse plane.

Working-Strength of Columns.—Much has recently been written,

and especially by German engineers, in regard to the so-called "fatigue" of iron, and the principles which should govern the arbitrary determination of the working-stress, or working-load. It would be impossible here to enter upon so wide a question, but the following points may be worthy of brief notice.

1. It is evident that the strength of a long column depends chiefly upon the modulus of elasticity, and to some extent upon the value of that modulus for stresses beyond the elastic limit. It is also known that for such stresses the value of the modulus is raised by the repeated application of stress; and it is therefore probable that the effect of such repetitions of stress would be rather to increase than to diminish the strength of a moderately long column.

2. It appears that the estimated flange-stress f which finally cripples the column is the same for all proportions of length to diameter; and the apparent breaking-stress, or breaking load p, is the load which produces the stress f in the extreme fibre. But it may be urged that instead of the crushing-strength f, the elastic limit or proof strength e ought to be taken as the starting point for fixing the proper working-load. In this case the value of the load or apparent stress p_e producing the proof-stress e, would be given by merely substituting e in place of f in the formula (6b), and the resulting values of p_e are represented in each diagram by the dotted curve marked "limit of elasticity."

It is worthy of notice that this would lead to a totally different result for the working-strength of all columns except very short ones; indeed the diagrams show that in long columns p_e is nearly equal to p. That is to say a load p_e producing the proof-stress e would be very nearly sufficient to produce the much greater stress f, and therefore would only require to be augmented by a very small quantity in order to break the column. This is readily explained by the fact that the deflection, the bending moment, and the flange-stress increase much more rapidly than the load; and therefore in any question relating to the working-strength of columns, the working-load must be distinguished from the working-stress.

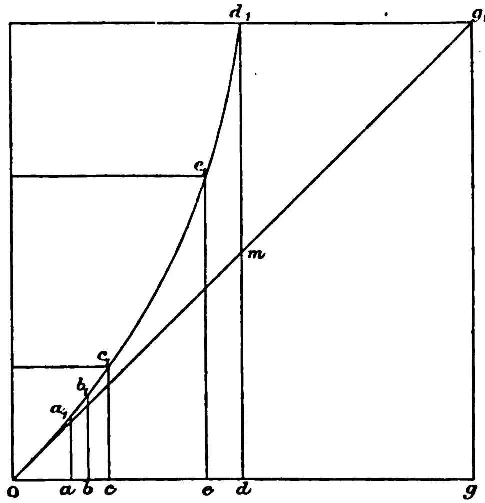
The way in which the stress increases with the load may be illustrated by means of the load-stress diagram Fig. 14, in which the vertical ordinates $a\,a_1$, &c., represent the maximum flange-stress due to any load O a, the co-ordinates being measured on the same scale in lbs. per square inch.

In the case of a very short wrought-iron column the stress is proportional to the load, and the diagram is the straight line Og_1

inclined at 45°; the breaking-load is denoted by Og, which is equal to the breaking-stress $g\,g_1$, or say 36,000 lbs. per square inch.

But in longer columns the load-stress diagram will be a curve rising more or less rapidly (according to the length of column) above the tangent Og_1. Thus, for example, the ordinates of the curve $O\,d_1$, represent the total flange-stress $f = p\left(1 + \dfrac{\phi\,p}{\rho - p}\right)$ for the case of a solid cylindrical column (round ends) in which the length is 25 times the diameter, which gives $\dfrac{l}{r} = 100$, and $\rho =$ 25,600 lbs. In this case the breaking-load is denoted by $O\,d$ equal

FIG. 14.



to 18,200 lbs., which corresponds with the value given in Fig. 6, while the breaking-stress is denoted by $d\,d_1$, which is equal to $g\,g_1$, or 36,000 lbs., and is made up of the direct stress $d\,m$, due to the load, and the additional stress $m\,d_1$ due to the bending moment.

Referring to this figure it would appear that the question of working-strength may conceivably be treated in several different ways; viz.

a. A factor of safety $F_1 = 4$ may perhaps be taken, and the working-load may be made equal to one-fourth of the breaking-load: so that in a very short column the working-load would be $\dfrac{36{,}000}{4} = 9{,}000$ lbs., or 4 tons per square inch.

b. The limit of elasticity may be taken at about $\frac{2}{3}$ the ultimate compressive-stress (or 10 to 11 tons), and a proportionately smaller factor of safety, or $F_2 = \frac{8}{3}$, may be applied to the proof-load, or the load which strains the flange up to the elastic limit; and by this method again the working load for the short column will be $24{,}000 \times \frac{3}{8} = 9{,}000$ lbs. per square inch as before.

c. The maximum working flange-stress may be taken at one-fourth the ultimate stress, or $\frac{3}{8}$ of the proof stress; and it is evident that this method also would give the same working-load as before in the case of the short column.

But in a longer column these three methods would give three different results. Thus in the case illustrated by the curve Od_1 the first method would give a working load of $\frac{18{,}200}{4} = 4{,}500$ lbs., or 2 tons per square inch, as denoted by the abscissa $O\,a$; and the diagram shows that in this case the maximum flange-stress would be about 5,000 lbs. only, as indicated by the ordinate $a\,a_1$.

To apply the second method, a horizontal line may be drawn at the elastic limit intersecting the curve at e_1, so that ee_1 denotes a stress of 24,000 lbs., and the proof load $O\,e$ is found to be about 15,200 lbs., which corresponds with the ordinate in Fig. 6; so that by this method the working-load would be $15{,}200 \times \frac{3}{8} = 5{,}700$ lbs. and the working-stress bb appears then to be about 6,700 lbs., or 3 tons per square inch.

To apply the third method, a horizontal line is drawn at the working-stress of 9,000 lbs., intersecting the curve at c_1, and the working-load will then be denoted by the abscissa $O\,c$, and will be about 7,500 lbs. per square inch.

It is not by any means intended to suggest that the last-named method could be safely adopted in practice; for it has already been shown that in very long struts this method would reduce the factor F_1, or $\frac{\text{breaking-load}}{\text{working-load}}$ to something dangerously near to unity. The first method, which is that usually adopted, is undoubtedly the safest in the case of long columns; but if this method is applied to struts of all proportions, the working-stress in long columns will be so small that it will probably be quite safe to disregard the demoralising effect which is supposed to be produced by alternations, or repetitions of stress according to the well-known views of Wohler and other German engineers.

Finally, it may be remarked that the working-strength of columns cannot be fixed with any logical precision until it has been determined what are the intended objects and functions of a

factor of safety. If the factor is intended only to cover any uncertainty as to the load, or direct straining-force, the first method is obviously the correct one; but if there are to be no mistakes in the computed load, but only in the computed resistance of the material, that method could hardly be applied consistently to columns of all proportions.

Concluding Observations.—The Author is well aware that the modified application of Euler's theory, above suggested, amounts only to a partial and imperfect treatment of the subject. The chief object has been to examine the bending stress which results from unequal elasticity, as affecting the strength of a column of ordinary proportions; excluding, as useless for this purpose, any reference to the exceptional features which arise in extreme cases —such as the looped curvature which the column may assume if its proportions are attenuated to those of a piano-wire; or the exceptional resistance which it offers when its proportions are reduced to those of a wafer, and which is evidently due to causes unconnected with the intrinsic strength of the material. Within these limits, it will be seen that the strength of struts, as affected by bending stress, has been calculated upon two assumptions, viz., that the inequality of modulus in any given bar is a constant quantity, and that the failure of the strut is marked by the insistence of a certain maximum stress f, which is regarded as the ultimate compressive-strength of the given material. In the case of cast-iron, neither of these assumptions is open to any serious objection; but in ductile or compressible materials, such as wrought-iron and steel, they are certainly arbitrary, and may be incorrect. In the case of these materials, there is of course some difficulty in fixing the value of the ultimate compressive-stress; and when the deflection of the column passes beyond the elastic limit, there can be little doubt that the inequality of modulus is subject to a progressive increase. The load-deflection diagrams taken from Mr. Christie's experiments, show that in some cases the inequality exists from the commencement, though in others it increases with the load; but the calculation can only indicate what would be the results of a given inequality, regardless of the steps by which it may have been reached.

If there is really no definable compressive-strength to be attributed to such materials as wrought-iron and steel, the only alternative must be to define the failure of the column by tracing the point at which it passes from stable to unstable equilibrium; and if the requisite data, in regard to the stress-strain relations beyond the elastic limit, were at hand, this method might no doubt be applied,

and would be far more complete. In the meantime, however, if the transition is examined with the aid of such information as can be gathered from the load-deflection diagrams, it seems probable that this alternative method would end in substantially confirming the results already obtained. The point of transition, or the point of indifferent equilibrium, may or may not coincide exactly with the assumed stress f, but it will at all events coincide pretty closely with the calculated breaking-load p. For when the column approaches the condition of indifferent equilibrium, as indicated by the increasing inclination of the curve, Fig. 5, becoming nearly vertical at the right extremity, the deflection and the fibre-stress rise together very rapidly through a considerable range, while the load p undergoes very little alteration; and therefore the correctness of the calculated breaking-load does not depend, except in a minor degree, upon an exact estimate of the ultimate stress f, so that the assumption of a constant compressive-strength, whether real or unreal, can hardly lead to any serious error discoverable by this method.

Broadly speaking, the question is whether the strength of struts must be regarded as an experimental quantity, varying in some unexplained manner with each change in the proportions of the strut, or whether, like the strength of girders, it can be calculated from the maximum local stress, on the assumption of a constant strength of material which does not vary with each change of dimensions. In the case of cast-iron there is no ambiguity about the value of the crushing-stress f; and the diagram, Fig. 8, shows that columns of all proportions give way at the moment when the crushing-stress is theoretically reached, or nearly so. In the case of wrought-iron, the "bulging or crippling stress" is of course not marked by any such distinct failure of the material; but the column gives way at a moment when this particular stress is theoretically reached, or nearly so. The results of experiment are not inconsistent with the assumption that the ultimate compressive strength is nearly constant, and subject to no greater variations than the ultimate tensile strength of the same material. Of course the ascertained results of experiment must always be regarded as the ultimate test of any theory; and they afford in themselves the best possible guide to practice, so long as the conditions of the experiment are the same as those which will obtain in the proposed structure. But this cannot be said in regard to many of the bending-stresses, which commonly take effect in compression members. For example, when the lattice-bars of a girder are riveted to the flanges, the deflection of the girder is known to

induce a bending moment at each end of the strut, which must greatly modify the stresses throughout its entire length. The strength of the strut, as affected by this bending stress, may be estimated by theory, but it cannot be inferred from experiments made with a strong and nearly rigid testing-machine.

In the same way there are other bending stresses, whose effects (in addition to those of unequal elasticity) may be computed on the same principles, if the assumption of a definite compressive strength of material may be permitted; and the error which may result from making the calculation on this assumption could hardly be so great as would follow from not making it at all. At the same time it may readily be admitted that a more complete investigation for the case of wrought-iron and steel is much to be desired.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been prepared.

APPENDIX.

Curve of the Elastic Column.—Let the curve A B C, Fig. 1, be constructed in the following manner. Divide the length of the chord A C = l into any convenient number of equal parts; and suppose a semicircular arc of the same length, and described with the radius $k = \frac{l}{\pi}$, to be also divided into the same number of equal parts. Then at each point of division on the straight line A C, set off the ordinates B D, K C, &c., proportional to the sine of the corresponding angle or arc on the circular curve. Thus if the length A C is divided into 180 equal parts, and if the central ordinate B D = δ is taken as unity, the values of the ordinates will be given by any table of natural sines.

Then taking A as the origin, and denoting the co-ordinates by x and y, the equation of the curve will be—

$$y = \delta \sin \frac{x}{k} \quad \ldots \ldots \quad (9)$$

and the curve will have the following properties.

If a tangent F B N is drawn parallel to A C, the inclination of the curve at any point G will be proportional to the area B D K G, and the off-set G N will be proportional to the moment of that area about K G as an axis. Thus at the point A the inclination of the tangent A T will be $\propto$ the area A B D, and the off-set F T = B D = δ will be $\propto$ the moment of that area about A.

For, differentiating y in respect of x, the inclination of the curve at any point will be expressed by—

$$\frac{dy}{dx} = \frac{\delta}{k} \cos \frac{x}{k} \quad \ldots \ldots \quad (10)$$

and putting $x = 0$, the inclination of the tangent A T, or the fraction $\frac{\text{A F}}{\text{F T}}$ will be—

$$\frac{dy}{dx} = \frac{\delta}{k} \quad \ldots \ldots \quad (10a)$$

(The length of the subtangent F T is therefore equal to k.)

The integral of the general equation will be—

$$\int y\,dx = \delta k \left(1 - \cos \frac{x}{k}\right) \quad \ldots \ldots \quad (11)$$

and the area of the half-segment A B C will be—

$$\int_0^{\frac{l}{2}} y\,dx = \delta k = \frac{\delta l}{\pi} \quad \ldots \ldots \quad (11a)$$

while the moment of that area about A is given by—

$$\int_0^{\frac{l}{2}} x\,y\,dx = \delta k^2 = \delta \frac{l^2}{\pi^2} \quad \ldots \ldots \quad (12)$$

(The distance from A to the centre of gravity of the area is therefore equal to k.)

The area of the half segment A B C is therefore equal to the inclination at A multiplied by k^2; and the moment of that area is equal to the off-set F T multiplied by k^3.

To show that the same proportion exists at all points in the curve, the point D may be taken as the origin, and the equation of the curve will then be $y = \delta \cos \frac{x}{k}$. The area of the figure B D K G will then be expressed by $\int_0^x y\,d\,x = \delta\,k \sin \frac{x}{k}$, which is equal to the inclination at G multiplied by k^2; while the distance x_o to the centre of gravity of the figure will be—

$$x_o = \frac{\int_0^x x\,y\,d\,x}{\int_0^x y\,d\,x} = x - k\frac{1 - \cos \frac{x}{k}}{\sin \frac{x}{k}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Therefore, multiplying the area of the figure by the arm $x - x_o$, its moment about K G as an axis will be given by $\delta\,k^2\,(1 - \cos \frac{x}{k})$; which is equal to the off-set G N multiplied by k^2.

When the elastic column (with round ends) is bent under the application of a vertical load P, the curve A B C of the bent column is itself the diagram of bending moments, so that at any point G the bending moment is $M = P\,y$.

In calculating the deflection curve for any known set of bending moments, it is generally assumed that the length of the curved beam A B C is practically equal to the chord A C. If the deflection were very great this would not be strictly true, but for all practical deflections of beams or columns it is sufficiently accurate; and making this usual assumption it is shown by the geometric theorem (referred to above) that the inclination of the beam at any point G must be proportional to the area of the diagram of moments B D G K, and that the deflection G N must be proportional to the moment of that area about G K as an axis.

It follows therefore that the sinusoidal curve above described is the curve of elastic deflection for any beam (of uniform section) under a set of bending moments proportional to the varying deflection y measured from the chord A C; and is therefore the curve of the elastic column.

Equilibrium of the bent Column.—Assuming as before that the deflection of columns within the elastic limit is in practice too small to diminish sensibly the length of the chord A C, it will follow from the geometric theory of deflection that the slope of the beam at A must be equal to the area of the diagram of moments A B D divided by $E\,I$, or by the modulus of elasticity, and by the moment of inertia of the beam. The maximum bending moment at B is $P\,\delta$, while the average value of $P\,y$ is equal to $P\,\delta\,\frac{2}{\pi}$; the area of the diagram of moments is therefore represented by $P\,\delta\,k$, and the slope at A must be equal to $\frac{P\,\delta\,k}{E\,I}$.

The elastic deflection F A is equal to that inclination multiplied by the length of the subtangent F T, and is therefore—

$$F\,A = \delta = \frac{P\,\delta\,k^2}{E\,I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Or more directly by the same geometric theorem, the deflection F A is equal to the moment of the area A B D (of bending moments) divided by $E\,I$,

or
$$F\,T = \delta = \frac{P\,\delta\,K^2}{E\,I}.$$

It follows therefore that the equilibrated load P can have only one value,

or $$P = \frac{EI}{k^2} = EI\frac{\pi^2}{l^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

This result arises of course from the fact that the bent column exhibits its own diagram of moments, as well as its own deflection curve, so that the ordinate δ is at once the measure of the bending moment and the measure of the deflection.

If the ends of the column were united by a string A C the equilibrated load P represents the tension that would be exerted upon the string by the resilient force of the bow $A_o B_o C$, acting in the line A C. The resilient force R is therefore a constant quantity for all moderate deflections of the bow, and is fixed by the equation $R = EI\frac{\pi^2}{l^2}$; or expressing R in lbs. per square inch of the columns section by ρ,

$$\rho = \pi^2 E\frac{r^2}{l^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

in which r denotes the radius of gyration.

So long as the chord A C is sensibly equal to the length of the column, the deflection due to any load cannot be calculated, and in any case if the load P is less than R, there can be no deflection whatever.

If the column were a perfectly elastic spring, it might perhaps be shown that a load P which is greater than R by an exceedingly small quantity, would be supported in equilibrium by the bent spring under a deflection great enough to sensibly shorten the chord A C; but in practice columns are not perfectly elastic watch-springs, and when bent to such an extent as to sensibly affect the above assumption, the limit of elasticity will be already exceeded, and the modulus of elasticity being thus reduced (on the concave side at least), the resilient force will be diminished rather than increased, and therefore R is practically the breaking-weight of the column.

Deflection of a braced strut with flanges of unequal stiffness.—If the round-ended strut illustrated in Fig. 4 is constructed as a girder with two flanges of equal sectional area united by cross-bracing, the modulus of elasticity in one flange may be somewhat greater than in the other.

Let $e_1 = \frac{1}{E_1}$ denote the specific compression of the inner flange;

$e_2 = \frac{1}{E_2}$ denote the specific compression of the outer flange;

$e = \frac{1}{E}$ denote the average compression or $\frac{e_1 + e_2}{2}$;

$p =$ the direct load in lbs. per square inch of total sectional area;

$r =$ the radius of gyration, or in this case half the depth of the girder.

Then the greatest bending moment being $M_o = P\delta$, the intensity of flange-stress due to that moment will be $\pm f_1 = \frac{p\delta}{r}$, and the average value of that stress throughout the length of the flange will be $\pm \frac{2}{\pi} \cdot \frac{p\delta}{r}$. Therefore the average stress on the inner flange will be $p\left(1 + \frac{2}{\pi}\frac{\delta}{r}\right)$, and on the outer flange $p\left(1 - \frac{2}{\pi}\frac{\delta}{r}\right)$.

Taking the half length A B, the difference between the lengths of the two flanges will be

$$\frac{p\,l}{2}\left(e_1 - e_2 + (e_1 + e_2)\frac{2\,\delta}{\pi\,r}\right) = \frac{p\,l}{2}\left(e_1 - e_2 + e\,\frac{4\,\delta}{\pi\,r}\right).$$

Dividing by the depth of girder, or $2\,r$, the slope at A will then be $\frac{p\,l}{4\,r}\left(\frac{4\,e\,\delta}{\pi\,r} + e_1 - e_2\right)$; and multiplying the slope by the length of the subtangent F T $= k$, the deflection F A will be given by—

Deflection $$\text{F A} = \delta = \frac{p\,l\,k}{4\,r}\left(\frac{4\,e\,\delta}{\pi\,r} + e_1 - e_2\right)$$
$$= \frac{p\,\delta\,e\,k^2}{r^2} + \frac{p\,l\,k}{4\,r}(e_1 - e_2);$$

or putting $$\rho = \pi^2\,E\,\frac{r^2}{l^2} = \frac{r^2}{e\,k^2},$$

$$\delta = \frac{p\,\delta}{\rho} + \frac{p\,l\,k}{4\,r}(e_1 - e_2)$$
$$= \frac{\rho}{\rho - p}\cdot\frac{p\,l\,k}{4\,r}(e_1 - e_2),$$

or $$\delta = \frac{\pi\,r}{2}\cdot\frac{e_1 - e_2}{e_1 + e_2}\cdot\frac{p}{\rho - p} \quad . \quad . \quad . \quad (17)$$

If the two flanges were subjected to the same compressive strain, their resistances would be respectively as E_1 to E_2, and the line of the resultant resistance would be moved from the axis of the strut by the eccentricity $\epsilon = r\cdot\frac{e_1 - e_2}{e_1 + e_2}$; therefore the above formula may be written

$$\delta = \frac{\pi\,\epsilon}{2}\cdot\frac{p}{\rho - p} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

The elastic deflection δ will therefore now have an assignable value, varying with the load p, but increasing very rapidly as p approaches to the value of ρ.

The deflection of the girder-shaped strut, as above determined, will be the same as that of a column of any solid section having the same moment of inertia. Thus a column of any symmetric cross-section may for this purpose be supposed to have the sectional area on each side of the neutral axis concentrated in two thin flanges, whose distance from the neutral axis is equal to the radius of gyration of the actual section.

In a column of solid section it is of course conceivable that the modulus of elasticity may vary in different parts of the section in a thousand different ways; but to estimate the limiting effect of such inequalities it may be supposed that the specific compressions e_1 and e_2 apply respectively to the effective flanges of the section placed as above described; and the deflection for a column of any section will then be given by formula (17) in which r is the radius of gyration.

This is equivalent to the assumption that the greatest probable eccentricity of elastic reaction is in all sections a certain fraction of the radius of gyration.

Strength of Columns with inequality of modulus.—In a round-ended column the greatest bending moment (at the centre of its length) will be $\text{M}_o = P\,\delta$; and if y denotes the distance of the extreme fibre from the neutral axis, the stress in that fibre due to the moment M_o will be—

$$\pm f_1 = \frac{p\,\delta\,y}{r^2} = \frac{\pi}{2}\cdot\frac{y}{r}\cdot\frac{e_1 - e_2}{e_1 + e_2}\cdot\frac{p^2}{\rho - p};$$

or putting $\phi = \frac{\pi}{2} \cdot \frac{y}{r} \cdot \frac{e_1 - e_2}{e_1 + e_2}$, the stress may be expressed by $\pm f_1 = \frac{\phi\, p^2}{\rho - p}$; and therefore the total compressive stress on the concave side, due to the direct load and to the bending moment, will be

$$f = p + f_1 = p\left(1 + \frac{\phi\, p}{\rho - p}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

This formula expresses the relation between the load or apparent stress p, and the greatest actual stress f on the concave side of the strut; and if f is now taken to denote the ultimate crushing stress or crippling stress of the material, the breaking-load p will be expressed by $p\left(1 + \frac{\phi\, p}{\rho - p}\right) = f$; and solving the implied quadratic, this gives for the breaking-load

$$p = \frac{\rho + f - \sqrt{(\rho + f)^2 - 4 f \rho (1 - \phi)}}{2 (1 - \phi)} \quad . \quad . \quad . \quad . \quad (20)$$

Therefore taking the greatest probable variation of modulus, and inserting the corresponding value of ϕ, this equation gives the lower limit for the breaking-weight of a column in lbs. per square inch.

It is obvious that this variation of modulus may either be regarded as a constant quantity existing from the commencement, or as a varying quantity caused by deflection beyond the elastic limit. To examine the effect in the latter case would certainly be more difficult, and the results could only apply to the further deflection of the column beyond the elastic limit, and not to any deflection within that limit. But the actual strength of the column appears to be limited by the presence of the *initial* inequality of modulus; because without it the deflection could never reach the elastic limit until the load was practically equal to the theoretic breaking-load R of the ideal column. The value of ϕ is therefore taken as a constant quantity; and the tables given in the Paper are calculated on the assumption that the stated inequality of modulus exists from the commencement. If the inequality increases after the deflection has passed the elastic limit, the result would be to lower the curve A C, but it may be observed that a considerable increase in the value of ϕ (beyond the stated value) would only produce a comparatively slight alteration in the curve.

(*Paper No. 2187.*)

"Experiments on a Direct-acting Steam-Pump."

By JOHN GEORGE MAIR, M. Inst. C.E.

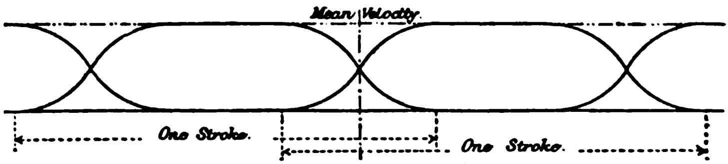
IN the Autumn of 1885 the Author casually heard that a system of pumping, invented by Mr. C. C. Worthington, of the firm of Henry R. Worthington, of New York, was in use in the United States, enabling a Worthington direct-acting steam-pump to work with as high a rate of expansion as any type of crank and fly-wheel engine, and at the same time exert a steady and uniform pressure on the pump-plunger. He therefore determined to investigate and test its working. The motions of both a steam-piston and a water-plunger being rectilinear, a connecting-rod, crank and fly-wheel having a rotative motion, are superfluous except for the purposes of expansive working or controlling the length of stroke. Mr. E. D. Leavitt, jun., who has a large and varied practice as a hydraulic engineer in America, explained to the Author generally the peculiarity of the design of the engine, expressed himself in the highest terms of its mechanical efficiency, and kindly offered to assist in any experiments it was proposed to carry out.

The Author took as an assistant, Mr. Henry Smith, Assoc. M. Inst. C.E., and in order that no question should be raised as to the accuracy of the necessary testing instruments, a circular orifice, through which to measure the air-pump discharge, three Kew-tested thermometers, an indicator, and also three tested Bourdon-gauges for water and steam pressures, were sent from England.

The inventor kindly placed an engine and its boiler entirely a the service of the Author, and expressed a wish that the trials should be as complete and exhaustive as it was possible to make them. The engine was at work at Brooklyn, New York, and was put up solely for experimental purposes. It pumped out of a well, and through weighted relief-valves back to the well, so that trials could be made which would have been impossible had the engine been performing the ordinary duty at a waterworks. To pump about 1,700 gallons a minute through weighted and spring-valves is a more difficult service than pumping against a head of water in a main. It was, therefore, evident that whatever results were obtained on the trials, they could be readily repeated and improved

upon in practice. Nearly twenty-five years have passed since the first Worthington compound-condensing engine was erected and set to work in America; since then great improvements have been made, and now these machines pump 40 per cent. of the total water-supply of the United States. The system, however, is not much known in England, and so little attention has it attracted, that there are no records of it in the Proceedings of this Institution, or in those of the Institution of Mechanical Engineers. In fact, it has not even been alluded to by the Authors of the various papers on pumping-engines that have been published from time to time. Practically the system consists of two independent engines and pumps lying side by side, the motion of one engine actuating the valves of the other. The delivery of water from the pumps is almost absolutely uniform, and although an air vessel is usually

Fig. 1.



Flow from Worthington Pump.

placed on the discharge chamber, it is generally water-logged, and the Author could not tell the difference in working either with or without air.

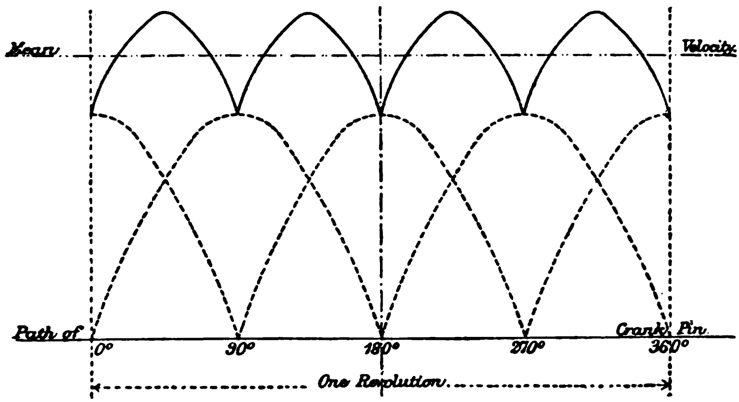
Fig. 1 represents, approximately, the flow from a Worthington pump at each point of the stroke. As soon as one pump begins to slow down at the end of the stroke the other pump starts, so that by combining the flow it will be seen how uniform it is. With any pump driven by a crank and connecting-rod, and even when two pumps are coupled on one crank-shaft at right-angles, great variation exists in the quantity of water delivered at different parts of the stroke, owing to the varying speed of the pistons, necessitating an air-vessel being placed on the delivery main.

The delivery from a compound rotative engine, with cranks at right-angles, working two double-acting pumps, supposing the connecting-rod to be indefinitely long, is shown by Fig. 2. The deliveries are added together and shown in full lines; the variation of flow in this case is sufficient to make the pressures fluctuate to such an extent that accidents are very liable to occur when working without air. The Author, in his own practice, has met with many cases where accidents have happened to the pump-work and rising mains, when through carelessness no air was in the vessel;

but with the uniform delivery of the type of twin-pumps before described an air-vessel is not needed, and it is this uniform delivery that permits the use of the engine for pumping through the oil-pipe lines where the friction in the mains amounts to 3,450 feet head at normal speed. With the single- or double-acting pumps first used for this service, where the flow ceased at the end of the stroke, the pressure gauge fluctuated hundreds of pounds on the square inch with a corresponding result of broken pipes and pumps.

The oil-pipe lines are of different diameters and lengths, and, taking as an example one that came under the personal notice of the Author, namely, 6 inches in diameter and about 30 miles long, through which two 10-inch double plunger-pumps were forcing oil,

FIG. 2.



VELOCITY DIAGRAMS.
TWO DOUBLE-ACTING PUMPS WITH CRANKS AT RIGHT ANGLES.

the main would contain, if filled with oil at a specific gravity of 0·87, over 750 tons, and as this weight may be considered as attached to the pump-piston, a very simple calculation will show what excessive pressures are set up when such a weight is moved at a variable velocity, and also as the pressure in the pump is nearly all due to friction in the main, which increases or decreases practically as the square of the speed of the flow in it, it can be seen that the only system of pumping capable of working with safety is that in which the delivery from the pump is uniform and regular at every part of the stroke. There are now on the oil lines some sixty or seventy compound condensing engines of various powers up to 600 or 800 HP. The service is a peculiar one, and the difficulties that have been overcome reflect the greatest credit on the engineers of the line.

The Worthington engine just referred to, although as economical in fuel as an ordinary Cornish engine, and more so if the first cost and the expense of foundations and houses is taken into account, can be beaten in economy of fuel by a well-designed compound rotative-engine working at a high rate of expansion. Mr. C. C. Worthington therefore applied himself to attach to his engine a form of compensation which would absorb or store up the excess of power at the steam end during the first part of the stroke, and give it out again during the last part of the stroke, when owing to expansion the steam-pressure falls below the water-pressure.

Now the main point to be observed in designing such an arrangement, is to obtain a perfectly uniform pressure on the pump plunger, so as to get a steady delivery of water. To effect this, compensators of many varied forms were schemed, and an experimental engine was made that would work up to about 150 HP., and a boiler arranged specially to supply it with steam. As it was almost impossible to obtain from the waterworks sufficient water for the engine, a well was sunk, the entire plant with experiments having cost about £10,000. The engine was worked for about a year and a half continuously, and found to be such a perfect success that several are now at work, and many others are being made on the system that was in practice found best.

If the steam-pressure diagrams of an expansive compound-engine are combined together, it will be found that there is an excess of pressure *a b* at the commencement of the stroke (Plate 8, Figs. 1) over the mean pressure decreasing to half-stroke, and after that point there is an increasing deficiency of pressure *b c*. This variation with a rotative-engine is taken up by the fly-wheel, but in the high-duty Worthington engine there are two small cylinders (by preference oscillating) which are attached to the piston-rod, containing water or air under pressure. Referring to Plate 8, Figs. 2, it will be readily seen that the excess of work *a b*, which is a maximum at the commencement of the stroke and decreases to nothing at half-stroke, is taken up by these small cylinders. Directly after half-stroke, when the steam-pressure is below the water-pressure, they give out work *h k*, which increases to the end of the stroke, so that if the work absorbed or given out in the compensators is combined with the steam diagrams, a perfectly steady pressure-line is obtained, and the engine makes its stroke at a uniform speed, so that a straight pump-diagram is obtained. The diagrams, Plate 8, Figs. 1, were taken from a high-duty pumping engine, working under ordinary service at New Bedford, Mass., U.S.A., the steam being expanded during the time it was taken some 10 or 12 times.

Engine Trials.—These trials were all carried out in a similar manner to those before made by the Author.[1] Plate 8, Figs. 3, give the general arrangement, plan of the boiler, engine, and pump, together with the position and details of the measuring tanks. The engine and pump are shown in Plate 8, Fig. 4. The feed water was measured in a cast-iron pipe, Plate 8, Fig. 5, with an overflow pipe in it, and its contents to the level of the pipe were weighed on tested scales many times over, the temperature being noted each time, so that the quantity of water in the pipe which was used as a feed measuring-tank may be relied on as accurate. From the pipe the water was run into a wooden tank, out of which it was taken by the feed donkey and pumped into the boiler. Mr. C. C. Worthington placed one of his water-meters between the feed-pump and the boiler, and the meter readings agreed within $\frac{1}{4}$ per cent. with the measurements made by the Author.

The boiler was of the Corliss type, vertical, 5 feet 4 inches in diameter by 14 feet high, with vertical tubes; and as the heat went direct from the fire through the tubes, and so heated the steam above the water-level, the steam was slightly superheated. A thermometer was fixed in the steam-pipe in the engine-house, the readings of which are given in the Tables. The steam-pipe went across a yard in the open air, but being well covered with non-conducting composition, and the steam being slightly superheated, condensation to any marked extent was prevented. The steam-jackets drained into a tank, which was carefully measured, and when full the condensed water was discharged into a drain, and the time noted. The working-steam, after leaving the engine, passed through the eduction pipe to an independent air-pump and condenser, worked by a separate engine. Both the feed-donkey and the air-pump engine were supplied with steam from a separate boiler, so that, in taking the efficiency of the engine into account, the work done by these pumps should be deducted. Their having a separate steam-supply did not, of course, affect the heat used by the main engine itself, but only the efficiency, that is, the relation of the indicated HP. to the pump HP. The steam from the main engine, after being condensed and passing through the air-pump, was delivered through a short length of pipe to the discharge-tank (Plate 8, Fig. 6), where it was gauged through a circular orifice 3 inches in diameter. The temperatures of injection and air-pump discharge were read, and the head measured every quarter of an hour.

[1] Minutes of Proceedings Inst. C.E. vols. lxx. and lxxix.

Eight new indicators, made by the American Steam-Gauge Co. (and which were checked with the English one) were on the steam-cylinders fixed close up to each head, and the diagrams were averaged by ordinates in New York, and checked by planimeters in England. Two counters were on the engine, which checked each other, and two tested water-pressure gauges were fixed on the delivery-main.

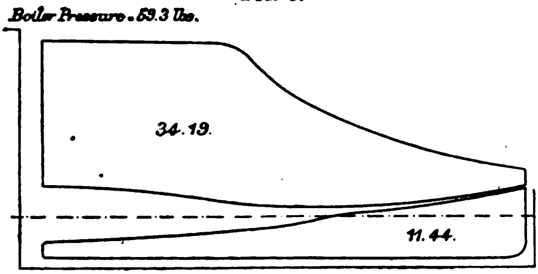
Five assistants were in the engine-room, and four in the boiler-house. A ship's chronometer was used for the time, and every quarter of an hour throughout all the tests gongs were sounded, one in the engine-room and one in the boiler-house, so that all observations were taken at the same instant, and the Author took personal observations all round every half-hour, so that no error could have crept in. Such detailed care was, however, not necessary, as the rejected heat was measured, and that gives the best check on the boiler-supply. The stroke was kept the full length, touching the cylinder-heads each time; and so regularly did the engine run that, for each trial, all observations were almost exact counterparts of each other. Independently of measuring the heat-supply, many interesting experiments were made; the engine was slowed down until it made one double stroke in a minute and a half. The pump had its pressure suddenly released, to show the safety of the engine, and the air-vessel was filled with air, and was also water-logged; the compensators were put out of gear; in fact, every experiment was tried that was of value. The Author made nine full trials, and Mr. Smith made three more after the Author had left New York. These trials were so regular that it is sufficient to give the details of three.

The absolute quantity of water delivered by the pumps could not be exactly ascertained; but even if the full displacement of the plunger was not made, it would not affect the results of the trials, as the pump HP. was taken from the actual pressure in the delivery main (as recorded by the gauges tested in England) against the area of the plunger, all connections and by-passes being carefully shut off and plugged before the trials. At the end of each stroke a pause is made, which allows the pump-valves to close before the return-stroke, and so prevents slip through them.

The average efficiency on the three trials is 91·5 per cent., but, from this has to be deducted the power it would require to work the air- and feed-pumps, and taking this at $3\frac{1}{2}$ per cent. would give a net result of 88 per cent. efficiency, or a higher value than is generally obtained by a crank and fly-wheel engine when the

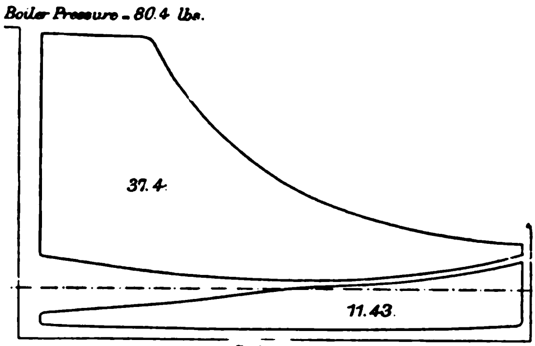
pump-valves are tight. This is what would be expected, as the

Fig. 3.



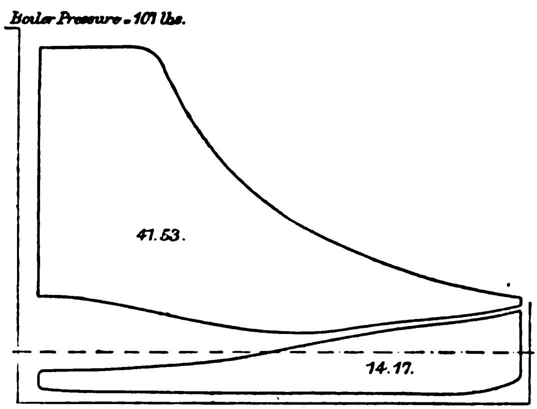
Scale $\frac{1}{80}$.

Fig. 4.



Scale $\frac{1}{80}$.

Fig. 5.



Scale $\frac{1}{80}$.

pistons of the compensating cylinders and trunnions certainly pro

duce less friction than the crank-shaft bearings, crank and cross-head pins, guide-bars, eccentric straps, &c., of a fly-wheel engine.

The piston-speed, as compared with the English practice, is very low, and naturally the repairs and renewals with these engines are of a most trivial character, even over long and extended periods of working. The foundations are simple, as the stresses are self-contained; in fact, the engine experimented with by the Author was hardly on any foundation, and when doing 165 indicated HP., as it did on one of the trials, it was perfectly steady, and worked without noise or vibration.

The following is a summary of three trials:—No. 1 on December 24th, No. 2 on December 19th, and No. 3 on December 22nd, 1885 (Figs. 3, 4, 5).

No. of trial	1	2	3
Double strokes per minute	45·0	39·26	40·10
Boiler-pressure . . . lbs.	59·3	80·4	101·0
Feed-water per minute (tank measurement) (Plate 8, Fig. 5) . . . lbs.	34·12	30·33	36·26
Jacket drains per minute . . . „	4·22	4·15	4·57
Temperature of steam	359°	376°	390°
Pressure on pump, including suction lbs.	78·5	80·5	97·0
„ in compensators . . . „	162·5	195·0	250·5
Mean pressure in high-pressure cylinder „	34·19	37·40	41·53
„ in low-pressure cylinder „	11·44	11·43	14·17
Temperature of injection	57·18°	57·10°	57·30°
„ air-pump discharge	84·95°	81·06°	89·50°
Head over centres of orifice . . . ft.	1·727	1·802	1·397
Air-pump discharge per minute . . lbs.	1,174·0	1,197·0	1,056·0
Injection water . . . „	1,144·0	1,171·0	1,024·0

Heat passing through Engine per minute—			
T U from boiler, saturated steam through cylinders	35,132·0	30,919·0	37,553·0
„ „ superheat in steam	853·0	772·0	906·0
„ „ condensation in jackets	3,794·0	3,677·0	4,003·0
Total	39,779·0	35,368·0	42,462·0
Heat retained in condensed steam	1,585·0	1,283·0	1,822·0
„ absorbed by injection-water	31,769·0	28,057·0	32,972·0
„ „ indicated work	5,096·0	4,621·0	5,579·0
„ „ radiation	440·0	440·0	440·0
Error	889·0	967·0	1,649·0
Total	39,779·0	35,368·0	42,462·0
Percentage of error to total heat passing through engine per minute	2·2	2·7	3·8

Indicated HP.	119·2	108·1	130·5
Pump HP.	109·3	97·9	120·4
Efficiency per cent.	91·7	90·6	92·3
Feed per I.HP. per hour through cylinders	15·05	14·53	14·57
" " " jackets	2·12	2·30	2·10
Piston speed per minute per engine . ft.	97·5	85·0	86·9
Boiler-pressure . lbs.	59·3	80·4	101·0
Number of expansions	9·2	13·2	14·1
T U per I.HP. per minute	334·0	327·0	325·0
Donkin's coefficient	273·5	265·2	260·6

T U per I.HP. per minute calculated from the temperature of the air-pump discharge	320·0	315·0	311·0
Lbs. of coal per I.HP. per hour, supposing feed taken from hot well and the coal to give up 11,000 T U per lb.[1]	1·74	1·72	1·70
Duty in 1,000,000 foot-lbs. of water raised per 112 lbs. of coal taking 88 per cent. efficiency	112·1	113·4	114·8
Disposal of Heat used—			
As indicated work . per cent.	13·3	13·5	13·7
Rejected heat and error. "	85·5	85·2	85·2
Radiation. "	1·2	1·3	1·1

In order to ascertain exactly the dimensions of the engine and pump under test, the cylinder and pump-covers were taken off, and gauges made of the diameters of the four cylinders and their piston-rods, and of the two pump-plungers and their rods; these gauges were brought to London and measured with a standard Whitworth rule, the mean areas and lengths being as follow:—

Low-pressure cylinders, area	1,013·0 sq. ins.
High " " "	251·0 "
Pump plungers "	235·75 "
Stroke, length	26·00 ins.
Clearance in low-pressure cylinder.	596·0 cub. ins.
" high " "	336·0 "

As before stated, the coal was not weighed; and in the Table above 11,000 T U is taken, so that these trials can be compared with those previously made by the Author.[2]

The engine worked perfectly on all the trials; was easily handled, and fully justified the opinion of its merits expressed by Mr. E. D. Leavitt, jun., and the inventor is to be congratulated on having achieved a result which could only have been arrived

[1] Minutes of Proceedings Inst. C.E. vol. lxx. p. 336.

[2] *Ibid.* vols. lxx. and lxxix.

at by a thorough knowledge of mechanics, coupled with great perseverance and enterprise.

In conclusion, the Author begs to tender his best thanks to Mr. C. C. Worthington; to his partner Mr. W. A. Perry, and also to Mr. Barr, Mr. Root, and other members of the staff, for their kind assistance, and for the careful manner in which they carried out the instructions of the Author relative to preparing the engine for testing.

The Paper is accompanied by several diagrams, from which Plate 8, and the Figs. in the text have been prepared.

(*Paper No. 2117.*)

"Viaduct over the River Esk at Whitby, and the Embankments and Culverts in the Ravines."

By FRANCIS FOX (of Westminster), M. Inst. C.E.

ON looking through the Proceedings of the Institution of Civil Engineers, the Author has found a marked deficiency in Papers which might serve as guides for the erection of an important brick viaduct, and it therefore occurred to him that a brief description of the work in question might prove of some service to the members of the Institution.

The viaduct forming the subject of this Paper carries the single line of the Scarborough and Whitby Railway over the valley of the Esk near Whitby, and in addition to spanning the river itself, crosses over the main line of the North Eastern Railway Company's Esk Valley Railway, and the Whitby, Redcar, and Middlesbrough Union Railway.

In designing this work it was necessary to provide for a structure, not only thoroughly substantial, but acceptable to the North Eastern Railway Company, and with this view it was decided to follow as closely as possible the general features of the graceful brick viaduct which carries the Cleveland Branch of the North Eastern Railway over the Skelton Beck near Saltburn-by-the-Sea.

The Author desires to take this opportunity of thanking Mr. Thomas Elliot Harrison, Past-President Inst. C.E., the Engineer to the North Eastern Railway Company, for his courtesy in placing at his disposal the drawings of the Saltburn Viaduct. When, however, the design of the Esk Viaduct came to be made, it was found necessary to depart from this type considerably.

The Harbour Department of the Board of Trade required considerable alterations in the plan of the river piers; the North Eastern Railway Company, for the purposes of their two railways, called for other variations; the level of the rails on the viaduct was raised some 20 feet, and these, with the peculiar nature of the foundations, all tended to change the character of the structure.

Borings were taken on the site of each pier and abutment, and in the case of all the piers rock was reached. In the case of the river piers the boring-tool failed to indicate anything except silt between the bed of the river and the rock, so that no difficulty was apprehended with the foundation.

Owing to the proximity of the viaduct to the sea, and the consequent exposure to corrosion, it was decided to avoid the use of ironwork, and to make a solid structure of brick in cement. The arches were designed to be approximately of 60-feet span, and the thickness of the piers at springing-line was kept as small as consistent with strength, their width being at that level 5 feet 6 inches. Piers Nos. 7, 8 and 9 being on the skew, and having unequal thrust, were thickened to 7 feet on the skew, or 6 feet 7 inches on square section at springing-line.

The greatest height from the bed of the river to rail-level is 120 feet. The number of arches is thirteen, and the total length of the viaduct is 915 feet (Plate 9). The land piers were sunk without difficulty by ordinary excavation, and a thoroughly satisfactory foundation upon the rock was secured in all cases, concrete made of broken slag with cement being placed under each pier to distribute the weight.

It was decided to adopt the Indian system of brick wells for the river piers, and as at low-tide there was a depth of only about 5 feet of water in the river, these were placed in position without difficulty.

A wrought-iron cutting edge was provided, the triangular space between the two sides of the shoe being filled with concrete in cement. On the top of this was built brickwork in cement of a cylindrical form on the outside, and corbelling inwards on the inside, until a brick well of 3 feet in thickness of wall was attained. By means of "grabbing" out the inside, the well was gradually sunk, and as it descended brickwork was added at the top.

It was soon found, however, that the "Priestman" grab or digger, although an excellent tool for removing material from the core, was useless for removing it from under the cutting edge, and in consequence of this Messrs. John Waddell and Sons, the Contractors for the railway, and to whose skill and energy the success of the work is greatly due, decided to make use of the grab described in the Paper on the Empress Bridge over the Sutlej.[1] By means of this excellent device the material was most efficiently

[1] Minutes of Proceedings Inst. C.E. vol. lxv. p. 248.

removed and the cylinder sunk some depth. But a much greater difficulty was to be encountered before the cylinder reached the rock, and this was due to a forest of old oak trees buried in the bed of the river. These oak trees were chiefly lying in a horizontal position and were of considerable size, many being from 2 to 3 feet in diameter. They were exceedingly tough and difficult to remove. An endeavour was made to remove these trees by the grab, but the attempt failed, nor could the water be pumped from the cylinders so as to allow them to be excavated in the dry. Dynamite was used, but the fear of injuring the cylinders prevented the employment of heavy charges, and consequently no satisfactory effect was produced.

It was feared that the pneumatic system of compressed air might have to be adopted, but as this should only be used when all other means have failed, Messrs. Waddell and Sons sent an experienced diver to remove the trees under water. The trees were chiefly cut out by saw, the resistance of the water preventing any percussive action being very effectual. When a large tree was encountered by the cutting edge of the cylinder, the diver scooped out a hole underneath, and having got into it, sawed upwards. To do this the diver had frequently to get outside of the cylinder, and when he had cut in as deep as he thought was safe, the chain from the steam crane was attached, and with a strong pull the end frequently broke off; but sometimes the operation had to be repeated.

When the tree was across both cutting edges, the diver had to saw right through at one end, which was very tedious work. One large Scotch fir, in particular, occupied from two to three weeks in being removed. When sawing failed, the chisel and hammer were used, the chisel being a large one, and the hammer having a short handle with a very heavy head. The axe was not much used. The steam crane, a powerful machine, proved very serviceable.

This was hazardous work, as the diver ran a great risk of having the air-tube cut; but so well did he complete his work, that in every case the cylinders were finally bedded on the rock, although in some of the piers the depth of oak timber to be penetrated was as much as 30 feet. Piers Nos. 6 and 10 are somewhat triangular in plan, they being the piers adjacent to the four skew arches over the river. Pier No. 6 had therefore to be differently designed to the others, and for this purpose two brick cylinders 20 feet in diameter were sunk, the interior being filled with concrete in cement.

The behaviour of the brick cylinders during sinking presented some curious features. A cylinder, say, 30 feet down would hang immovable for days, held entirely by the side friction of the silt; this, too, although everything had been carefully cleared away from under the cutting edge, and as deep a hole as possible taken out below it with the grab, and several hundred tons of rails stacked on it. Suddenly, without warning of any kind, when nothing was being done, the cylinder would silently and swiftly sink several feet. These unexpected but welcome subsidences (which were not the rule, however), generally occurred about the half-ebb following a high-tide. Generally the cylinders sank gradually and almost imperceptibly when cleared of the ancient timber. The greatest difficulty encountered was that of keeping the cylinders as they sunk for the first 15 feet vertical and in true position; this difficulty was owing to the buried tree-trunks constantly encountering the cutting edges at one point and tilting the cylinders, an action greatly assisted by the heavy "freshets" to which the river is liable in the autumn and winter months, and the rapid scouring round the cylinders caused thereby. The difficulty was met by careful watching and constant checking, and overcome by weighting the cylinders with rails on their high sides, or even grabbing the river-bed outside to draw them back. When, however, the cylinders had reached a depth of 15 or 20 feet, neither the trees nor the floods disturbed them any more.

It was considered unadvisable to employ pumps during the process of concreting, consequently the concrete was lowered into the water in "pigeon trap" boxes, and, after being by this method deposited at the bottom of the cylinder, it was carefully levelled in and trodden down by the diver. It was found that when a layer of concrete of 4 feet in thickness had been placed in position and allowed to set, the cylinders could be pumped free of water, and the remainder of the concrete put in dry.

Piers Nos. 5, 7, 8, and 9, each consist of three brick wells 14 feet in external diameter, and all these were sunk and concreted in a similar manner. In the case of pier No. 9, as the cylinders when in permanent position were near the face of the rock in the ancient bed of the river, the gravel and silt in the existing river-bed were removed until the rock was exposed at the face of the pier, and a concrete apron was put in to provide against the possibility of injury from scour in the river.

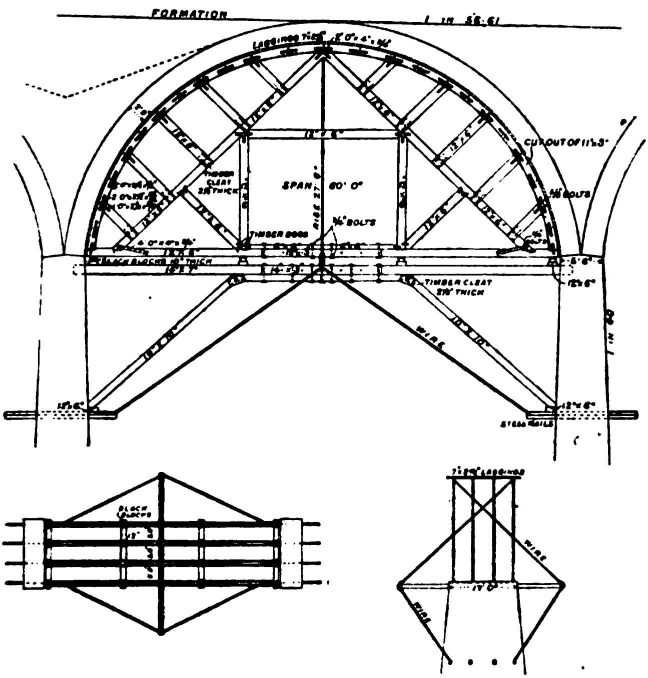
When the brick cylinders were brought up to above low-water mark, and had been filled with concrete, semi-circular arches were turned between the cylinders, and upon these was constructed a

continuous pier of brickwork. In order to ensure the two outside cylinders receiving their proper share of the weight, the pier was tapered upward.

Stone springer-beds were provided for the skew arches, and in these "checks" were cut to receive the various rings of brickwork. The entire structure, with the exception of the haunching of the arches, is built in cement.

The arches are seven rings, 2 feet 9 inches in thickness. The spans vary from 55 to 65 feet, with a uniform rise of 27 feet

Figs. 1.



6 inches. The arches are backed up with brickwork in mortar, which with the arches were coated with asphalt about $\frac{3}{4}$ inch in thickness, laid on in two coats; the intervening space between the brickwork and the permanent-way is filled with clean ashes. Independent centres being necessary, eleven of the arches were thus centred at the same time, the remaining two being provided with the centres of arches Nos. 1 and 2.

Figs. 1 represent the description of centre employed. This was of pitch pine, and consisted of four ribs; each rib was carried on

a foot-beam built into the piers at the end, and these foot-beams were further strengthened by diagonal struts from the piers, in which lengths of steel rails were built for the purpose. Lateral stability (until the weight of the arches came on) was obtained by steel-wire ropes, secured by tightening screws to anchor piles driven into the ground.

In consequence of the exposed position of the viaduct, it was necessary that all the arches should, when once commenced, be keyed in as quickly as possible. The brickwork of the arches was commenced on the 13th of May, 1884, and the last arch was keyed in September of same year.

The width of the viaduct between the parapets is 14 feet 6 inches on the straight, and 15 feet on the curve.

The parapets are 4 feet 6 inches in height above the rail, and are 18 inches in thickness.

Refuges for the plate-layers are provided over each pier.

The quantities of work in the structure are as follow:—

	Cubic yards.
Excavation in foundations of abutments and land piers	3,446
" cylinders and apron	3,726
Concrete in cement in foundations	1,733
" " cylinder and apron	1,444
Brickwork in cement ($1\frac{1}{2}$ to 1) in cylinders and jack arches	2,887
" " (4 to 1) in interior of cylinders	206
" " 6 to 1	7,170
" " in arches	2,698
" lime in haunching	976
Ashlar in springers of skew arches and coping	2,627 cub.ft.
Timber	1,473 "
Ironwork in drain-pipes, &c.	17 cwt.
Ashes, filling-in of spandrels	1,248 c.yds.
Total number of bricks in structure about	5,000,000
	Tons.
" weight of entire structure	25,700
Pressure per square foot on cylinders at level of river bed	$3\frac{1}{2}$
" " " bottom	$5\frac{1}{4}$
" " brickwork at springing of arches	7·9
" " " crown "	3

For the purposes of calculating the stability of the structure under wind-pressure, an isolated pier, No. 4, with its two adjacent half-arches, was taken, and over the whole surface of the structure, including a passing train, a pressure of 56 lbs. per square foot was assumed. The results are as follow:—

		Foot-tons.
The moment of stability	=	21,600
And the moment of overturning	=	5,037
Giving a factor of safety of		4·28

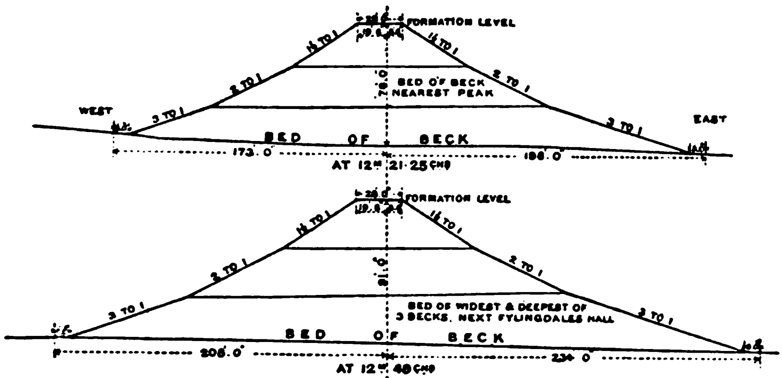
In the above no credit has been taken for the horizontal continuity of the structure, which in fact acts as a girder, held at each end by the abutments, thus offering great resistance to any horizontal force.

The first spadeful of earth was turned in the foundations early in October, 1882, and the first engine ran on the bridge on the 24th of October, 1884, a period of a little over two years.

The whole structure was completed without the loss of a single life. Only two serious accidents occurred to the men employed; both were falls from the piers, and both men recovered.

On the same railway several deep ravines had to be crossed; and, as the formation is glacial drift, it was decided to fill these with solid embankments rather than run the risk of the bad

Figs. 2.



foundations which would have been encountered had viaducts been adopted. The height of one of these embankments was 85 feet on the centre line (or 100 feet at the lower foot of the slope), and others were 76 feet and 74 feet.

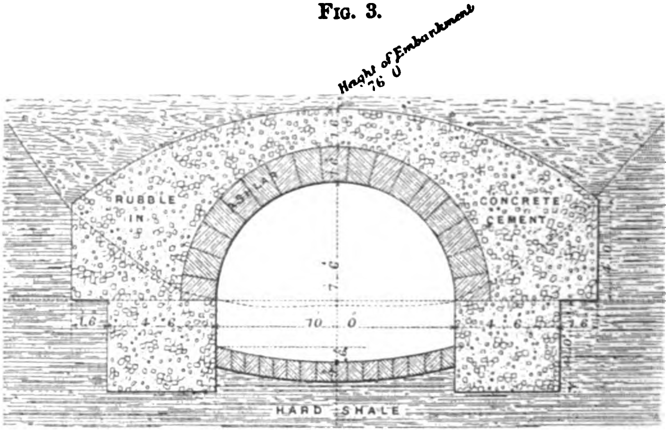
To avoid risk of slips, these embankments were tipped with varying slopes. Thus for the bottom third of the height the slopes are 3 to 1, for the middle third 2 to 1, and for the remaining or upper third 1½ to 1. This precaution was fully justified by the treacherous character of the clay, and the result has been most satisfactory.

Cross-sections of two of the ravines or becks are shown by Figs. 2.

The culverts for these high embankments gave rise to much careful investigation. The largest is that carrying Mill Beck, Fig. 3; it is 10 feet in width, with a height of 7 feet 6 inches,

the height of rails above the invert of the culvert being 86 feet. The barrel of the arch consists of ashlar masonry 18 inches in

Fig. 3.

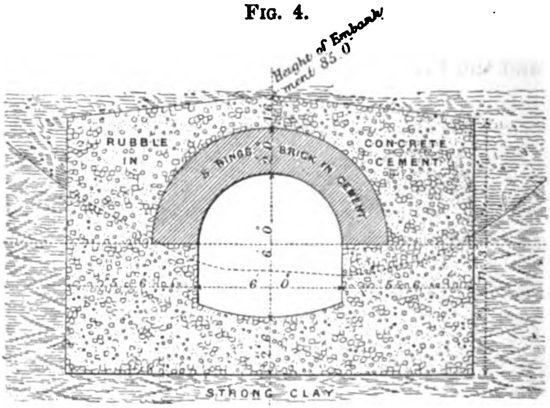


13 M 38 Chs MILL BECK.
A deep & narrow gorge, with perpendicular Shale sides, fall 1 in 55, Length of Culvert 330.0"

Scale 8 Feet = 1 Inch.

thickness, strengthened by a covering of rubble concrete in cement. Owing to the liability of heavy floods, an invert 9 inches in thickness was provided. The length is 330 feet.

Fig. 4.



12 M 47 Chs ALLISON HEAD BECK.
A wide & deep ravine, with treacherous slipping sides of a slope of 2½ to 1 fall of beck 1 in 34, Length of Culvert 375.0"

In the case of the Allison Head Beck (Fig. 4), the height of the rails above the invert of the culvert is 95 feet. The arch is 6 feet

span, with five rings of brick in cement, protected by a covering of rubble concrete in cement. The length is 375 feet.

Screens of iron rails are provided above the upper entrance to these culverts, for the purpose of intercepting trees and débris.

In carrying forward the high embankments from each side of the ravines, the precaution was always taken of previously covering the culverts from end to end with a depth of from 20 to 30 (or even more) feet of earth, tipped down a spout and wheeled forward over the culvert. This was to protect the culvert from the side-long thrust and irresistible "ploughshare" action of the advancing toe of the embankment in the soft and treacherous ground. The becks crossed were generally of a steep gradient, and had very steep slopes, heavily wooded; hence it was necessary not only to provide for permanently, but to contend with several times whilst the culverts were in progress, floods which would convert in an hour a trickling rivulet into a raging torrent 3 or 4 feet deep, carrying along with it a mass of débris, gravel, and boulders. The foundations of the culverts were everywhere taken down to rock or strong clay, and the faces protected by pitched aprons and wing-walls.

Mr. Charles Arthur Rowlandson, to whom much of the credit of the work was due, was the Resident Engineer. The Contractors, Messrs. John Waddell and Sons, were well represented by Mr. Percy N. Meares.

The Paper is illustrated by several drawings, from which Plate 9 and the Figs. in the text have been prepared.

(*Paper No. 2100.*)

"Heliography; or, the Actinic Copying of Engineering Drawings."

By Benjamin Howarth Thwaite, Assoc. M. Inst. C.E.

The advantages of rapidity and fidelity of reproduction possessed by the actinic copying method are already well known; but the following notes on the most modern practice may be interesting to engineers.

Sir John Herschel, who was probably the first to employ photographic printing for purely scientific purposes, used a cyanotype process for reproducing his astronomical tables.

In 1840, a Paper was submitted to the Institution by Mr. Alexander Gordon, entitled, "Photography as applicable to Engineering," in which Mr. Gordon described Daguerre's discovery, pointing out the advantages it offered to the engineering profession, and recommending the silver printing as a ready means of obtaining duplicates of drawings.[1] Engineers did not, however, employ heliography to any great extent until the ferro-prussiate, or cyanotype, commonly called the blue-copy process, was introduced, when the advantages of cyanotype heliography became manifest; and, in some instances, the simple apparatus required for this method has been extended into complete photographic studios. The Midland Railway Company; Krupp, of Essen; Sir W. Armstrong and Co., of Newcastle; and Siemens and Halske, of Berlin, have photographic departments. The latter firm, in its Berlin establishment, employs a powerful electric arc-light of 6,000 candles, around which the printing-frames are placed; and both the platinotype and Pellet processes, have given successful results with the arc-light.

The heliographic apparatus includes tracing paper or cloth, printing-frames, a developing bath, non-actinic arrangements, and cases for storing paper.

Thin bluish tracing-paper is the best; the more translucent it is, and the stronger, the better. After the tracing has been made,

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[1] Minutes of Proceedings Inst. C.E. vol. i. (1840), p. 57.

it should be preserved from light, as exposure to light gradually renders tracing-paper more opaque. The tracing should never be folded, but kept perfectly flat, or rolled. Drawings on ordinary drawing-paper, or from illustrated papers, can be copied if they are exposed to the light sufficiently long, the duration of exposure depending on the thickness or transparency of the paper. When the drawing only shows half the section of the figure to be traced, the full section can be shown by tracing the other half on the back of the tracing-paper; the sun-copying reproduction is precisely the same as if the tracing had only been made on one side; and all the writing and dimension should be on the front side. Translucent drawing parchment paper, specially prepared for the sun-copying processes, can now be obtained. The dimension-lines for the ferro-prussiate, or cyanotype negative, should either be dotted or ruled in Indian ink, chrome yellow, or raw sienna; or if in Prussian blue or carmine, the colours should be made more opaque by a slight admixture of flake, or Chinese white. In copying by the ferro-prussiate or cyanotype processes, the sectional parts of the figure should be cross-hatched; or the sectional parts can be coloured with shades slightly less opaque than the linear portions, by the addition of an opaque colour, such as Chinese white; and as these sectional parts of the print are reproduced almost white, they can be coloured with the usual conventional colours, which could hardly be done on a blue ground. The Pellet and Shawcross methods allow of the ordinary conventional colours being used without this preliminary preparation. The best Indian ink should be employed, its opacity being increased by the addition of gamboge or chrome yellow.

The printing-frame is the most important part of the apparatus, as upon its merits depends much of the success, both as regards accuracy and legibility. If the tracing and the sensitized paper are not brought into close contact with each other, the actinic rays pass under the lines of the drawing, which are thus either obliterated or contorted. The pressure should be uniformly distributed, to bring the sensitive and tracing papers into close contact, as any local pressure produces irregularities and false impressions, causing wrinkles in the tracing-paper, the shadows of which are reproduced. In order to test the shrinkage of the paper, the scales should be drawn on the tracing in two directions, at right angles. The shrinkage of strong Pellet or cyanotype paper is equal to 0·005.

The form of frame is very simple. The glass should be ¼-inch plate, free from blemishes; and the Author has used 26-oz. glass

for small frames. A piece of soft felt, ½ inch thick, the full size of the frames, should be used to equalise the pressure, or a piece of folded flannel will serve the purpose admirably; and it is well to use indiarubber sheets, sewn to the edges of the flannel or felt.

The most useful sizes for the printing-frame are 12 by 14, 19 by 26 for Royal, 22 by 30 for Imperial, 30 by 43 for Double Elephant, and 40 by 56 inches.

The method devised by the Author for hanging the printing-frames is shown in Fig. 1, whereby the printing-frame can be inclined at any angle. This frame is adapted for offices in which space is limited, and in combination with the Author's arrange-

Fig. 1.

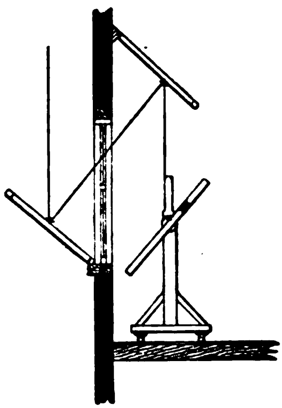
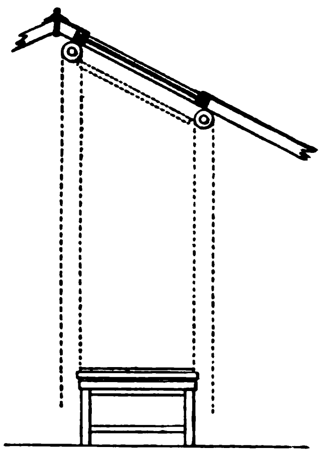


Fig. 2.



ment of developing bath, forms all the apparatus necessary for the Herschel, cyanotype, and Shawcross processes. Where diffused light alone reaches the office, owing to the obstruction of neighbouring buildings, reflecting frames can be used (Fig. 1); or the printing-frame may be hoisted to the roof fanlight by pulleys (Fig. 2).

The tracing is placed with its figured face next the glass, and the sensitized paper, with its prepared face next to the tracing, is carefully and uniformly pressed into contact with it. The felt is next laid upon the paper, in such a way as not to disturb the position of the tracing or the sensitized paper. The back board is then placed on the felt, the clamping-bars are fixed in position, and the face of the frame is exposed to the sun at such an angle as

to be as nearly as possible at right-angles to the solar rays. There should not be any obstacle, such as window-mullions, &c., intervening between the printing-frame and the source of light, as any partial obstruction of the rays would produce an imperfect copy. Where practicable, the printing-frame should be exposed in the open air, to the full rays of the sun, or to the brightest part of the sky, preferably placing the face of the frame flat, so as to get the direct rays from the zenith, and with no wall near it to obstruct the light. If such a wall exists, it should be coloured white, to reflect as much of the actinic light as possible. If this is not possible, the frame should be exposed for half the time of exposure turned in one direction, and then reversed end for end for the remainder.

Instead of springs or clamps on the printing-frame, use may be made of Street's copying-frames, with an air-cushion inflated by simply blowing, and exerting a uniform pressure over the whole surface of the frame.

The sensitive paper should be taken from its case in non-actinic light. This is especially important with papers sensitized by processes Nos. 3, 4, 5, and 6, described further on.

The Author has employed yellow window-blinds, which have proved sufficiently effective in obstructing actinic light; and amber-coloured glass may be used, or ordinary windows can be converted into non-actinic ones by being covered with ruby, yellow, or amber-coloured glacial paper. The light of any office can thus be made non-actinic at a slight expense. The Author sensitizes the paper in the evening, using a ruby lantern. When the paper has been prepared by the cyanotype processes, or the gallic acid process, non-actinic arrangements are superfluous, as these papers may be freely handled in the diffused light of an office for the short time required to cut and place the sensitized paper in the printing-frame.

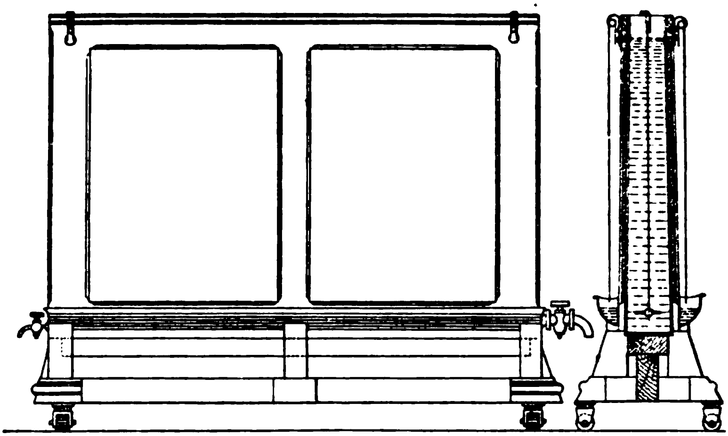
The developing bath should be slightly larger than the paper to be treated. For acid solutions, the bath should be of earthenware, papier-maché, vulcanite, or enamelled iron; but for most of the solutions mentioned in this Paper, the bath may be of zinc, or of wood lined with guttapercha, or sheet lead.

For the Pellet process, two trays lined with guttapercha, and one zinc tray, will be required. A copious supply of water to the bath, from a 1-inch rubber tube attached to a water-tap, will be found a great advantage. The print, on its removal from the frame, should be rapidly transferred to the bath, and after being immersed in pure water until it is completely developed, should

be withdrawn and hung up on a line, or on glass rods with clips, until the water has drained off; and blotting-paper will then effectually remove the remaining moisture.

A wooden bath may be employed if, when perfectly dry, it is treated with a varnish of ½ lb. of common brown resin and 2 oz. of beeswax. The developing bath designed by the Author (Fig. 3) is well suited for offices where space is limited, as it is more portable than the flat form of bath, and occupies little space; the water clears itself from the dissolved salts, and the prints are more easily developed. The prints, when in the bath, are removed from the light, and when withdrawn they can be hung on the

FIG. 3.



DEVELOPING BATH.

drying-rods at the sides of the bath, the water draining into the troughs at each side.

The sensitized paper should be preserved from damp and the light in zinc cases. Where the locality is a damp one, it is a good plan to have the lid fitted to hold a piece of calcic chloride, to absorb the moisture.

No. 1.—*Cyanotype Sensitizing Process* (*Herschel's*).—White lines are produced on a blue ground with a solution of 140 grains of ferric-ammonic citrate, 120 grains of potassic ferri-cyanide, and 2 oz. of distilled water; and the solution should be kept in a stoneware vessel.

This process depends upon the actinic action of light reducing the ferric salts to a ferrous state under certain conditions, one of

which is the presence of organic matter, such as the albumen or other size contained in the paper. The ferrous salt then combines with the potassic salt to form Prussian blue, which is insoluble.

The sensitizing solution should be applied to cream-laid paper, rolled and well sized by a flat damping brush, 6 inches wide, or a tuft of cotton-waste; and the paper should be allowed to dry in the dark. The solution should be applied uniformly, and sufficiently just to cover the surface of the paper. After drying in the dark, the paper should be rolled and stored in special cases.

Two or three minutes' exposure to the sun at noon, and thirty minutes in the afternoon, is sufficient when newly-made sensitized paper is used. The exact degree of printing during exposure can be ascertained by the use of a small printing-frame, in which sensitized paper should be exposed along with that in the larger frame, and under precisely similar conditions. Another method is to allow a part of the sensitizing paper to protrude from behind the tracing. The effect of the degree of exposure can be ascertained by watching the varying colours of the paper, which, with the blue negative cyanotype processes, change from an initial yellowish green to a bluish green, then to bluish grey, and finally to an olive green, when the exposure is complete.

A 6,000-candle arc-light is equal to half the actinic effect of ordinary sunless noonday light, and equal to one-sixth of the actinic effect of unclouded sunlight. At a distance of 5 feet from an electric arc-light of 6,000 candles, an exposure of thirty minutes is required for paper sensitized by the Pellet process, and a little longer for the other cyanotype processes. As the argentic paper is four times more sensitive than the cyanotype paper, about ten minutes' exposure only is needed for paper sensitized by the argentic nitrate process. By arranging several printing-frames in a circle of 10 feet around the arc-light, as many as eight large copies can be made at the same time.

When it is required to copy during dark days, and where electric arc-light is not available, actinic light may be produced by a deflagrating mixture of 8 parts of potassic chlorate, 4 parts of antimony sulphide, 2 parts of sulphur, and 2 parts of magnesium dust; but it is only suitable for the highly sensitive argentic nitrate, and platinotype processes, and must not be pounded or otherwise mixed in a mortar.

The development is effected by thoroughly washing the print in pure water, in the bath, for a few minutes. A little hydric chloride is occasionally added to the water to increase the intensity of the blue ground, which may be converted into black by

first immersing it in a bath of caustic potash, and afterwards in one of tannic acid. Development is considerably accelerated by the use of water at 90° to 100° Fahrenheit. Only sufficient paper for two months' use should be obtained.

No. 2.—*Cyanotype Process* (*Marion's*).—White lines on a blue ground are also produced by a sensitizing solution composed of $9\frac{3}{8}$ oz. of ferric-ammonic citrate, and $6\frac{1}{4}$ oz. of potassic-ferric oxide, dissolved separately in pure water, and then made up to 1 quart.

Both processes Nos. 1 and 2 give good results. When positive prints (or blue lines on a white ground) are required, the sensitive paper should be of the thinnest possible description that will permit the solution to be applied without sinking through it. This thin paper should be then used in the manner described for taking a negative copy (or white lines on a blue ground), this negative copy being used instead of the tracing, and the ordinary sensitized paper placed behind it in the ordinary manner. The exposure must be considerably prolonged (from three to four times at least); and the development also occupies a longer time.

To effect alterations or additions on negative prints, the following methods may be adopted. White lines may be obliterated by applying a quill-pen or brush dipped in the sensitizing solution, and then exposing and developing as already described. Additions may be made with flake, or Chinese white; but a more effectual method is to use a quill-pen, or brush, dipped into a solution of 40 grains of potassic carbonate in 1 oz. of water. Immediately after applying the potash, the paper must be carefully dried with blotting-paper, otherwise the effect of the solution will spread.

No. 3.—*Positive Cyanotype Process* (*Pellet's. Blue lines on a white ground*).—According to an admirable treatise,[1] this process is the most important of the existing sun-copying or photographic-tracing methods. It is widely used by engineers on the Continent; it gives very distinct prints, and depends upon the reduction of an organic ferric salt to a ferrous salt by actinism. Prussian blue is formed by the reaction of ferric compounds with potassic ferrocyanide; and white ferrous compounds form a white salt with the same reagent. If the paper sensitized by the Pellet process was introduced into the ferrocyanide developer without exposure, it would become entirely blue, owing to the uniform deposition of Prussian blue. Should any part have been sufficiently exposed to

[1] "Die Modernen Lichtpaus Verfahren, zur Herstellung exacter Copien nach Zeichnungen Stichen," &c.

the light, the paper will remain white owing to the complete reduction of the iron from the ferric to the ferrous state, the persalt of iron becoming reduced to the state of protosalt wherever the sensitive paper is unprotected by the opaque lines of the tracing. Hence the Pellet process produces dark blue lines on a white ground. The solution is made with 3 parts of sodic chloride, 8 parts of ferric chloride, 4 parts of hydrogen tartrate, and 100 parts of water; and it is thickened by the addition of 25 parts of powdered gum-arabic. The paper should be fastened down by pins, and the solution applied in the usual manner. The paper should be dried as quickly as possible, to keep the sensitive coating as much as possible on the surface of the paper.

In full sunlight, one to two minutes' exposure is sufficient; but in dull weather, considerably longer time is required. With the electric arc-light, the time of exposure varies from twenty minutes to half an hour. The progress of actinic action on the Pellet paper may be tested by inserting several test-slips beneath a similar piece of tracing-paper, on which some lines have been drawn, withdrawing these slips at different periods during the exposure and inserting them in potassic ferrocyanide, until the exposure is found to be sufficient. By adopting this simple actinographic method, much disappointment may be prevented.

The paper sensitized by this process will keep for days after exposure before developing, so that when a considerable number of sun-copies are required, it is advisable to expose all of them when the light is good, and to develop them subsequently at leisure. The print should be transferred into a saturated solution of potassic ferrocyanide, not immersed, but floated with the prepared face next the solution. By simply turning up the edges of the print, the developing solution is prevented from reaching the back of the print. The development is rapid, one minute being generally sufficient. A blue coloration of the ground is a proof of insufficient exposure; while weakness of the lines indicates over-exposure. If the exposure has been sufficient, the paper may be left for a considerable time in the developing bath, to increase the definition of the lines. On the contrary, should the exposure have been weak, the print must be submitted for a short time only to the influence of the potassic ferrocyanide, to avoid blue spots caused by unreduced particles of iron.

After the completion of the development, the print should be floated face downwards upon clean water; and in about two minutes, it should be immersed in an acid bath, composed of 8 parts of hydric chloride, 3 parts of hydric sulphate, and 100 parts of

water. From six to eight minutes is sufficient time to allow for the acid reaction on the iron compounds, and for the removal of the redundant iron compounds by the acid. The print should next be thoroughly washed with water, and dried. Any blue discoloration may be remedied by a dilute solution of potassic hydrate, applied with a quill-pen, or brush, and blotted.

The potash solution is composed of 1 part of potassic hydrate and 28 parts of water. A solution, termed blue solving, is provided for making alterations, or additions, on paper prepared by this process.

When the helios produced by the Pellet process are discoloured, they may be effectually bleached by a 4 per cent. solution of hydric sulphate in summer; and in winter this may be increased to 6 per cent.

When the cyanotype, the Pellet, or Shawcross prints are intended for the workshop, they should be saturated with white, hard varnish. This will prevent the penetration of oily matters, grease, &c., and the adhesion of dirt. For rough work, the prints should be mounted on linen, with fresh, white paste, entirely free from acid and alum, applied to the back of the print.

No. 4.—*Positive Cyanotype Process* (*Pizzighillis'. Dark blue lines on a white ground*).—This process is very similar to Pellet's; the solution consists of 5 parts of powdered gum-arabic dissolved in 25 parts of water, 1 part of ferric-ammonic citrate with 2 parts of water, and 1 part of ferric chloride with 2 parts of water, mixed in the proportion of 30 parts of the first, 8 of the second, and 5 of the last. At first the mixture is limpid, but it soon grows thicker. It should be applied to the paper immediately after mixing.

The exposure is the same as for Pellet prints.

The developing solution is composed of 1 part of potassic ferrocyanide and 5 parts of water. This solution should be carefully applied to the face of the print with a large camel's-hair brush, when the delineations in dark blue will at once appear. As soon as the drawing is quite clear, the prints should be placed in a solution of 12 parts of hydric chloride and 10 parts of water. The ground will then become quite clear and white, and the gum will be removed. The print should be finally washed in clean rain-water.

No. 5.—*Nigrographic Process* (*Black lines on a white ground*).—This process, although complicated, and requiring scrupulous care in manipulation, is worthy of a place, because of the peculiarity of the reagents used, and the method of operation.

The solution employed consists of 25 parts of gum-arabic, 7 parts of potassic bichromate, 1 part of alcohol, and 100 parts of water. This solution should be applied to thoroughly sized paper, dried, and kept in a dark place.

The exposure is the same as in the ferro-prussiate, or cyanotype processes. After exposure, it should be placed in cold water for twenty minutes, to wash out the unchanged bichromated gum. After drying, it should be treated with a mixture of 5 parts of shellac, 100 parts of alcohol, and 15 parts of finely ground lamp-black. This black mixture should be carefully applied, by means of a sponge, to the face of the print, which should then be immersed in an acid solution of 100 parts of water and 3 parts of hydric sulphate. The superfluous black colour can be removed by a soft camel's-hair brush; and the delineations appear in black lines on a white ground.

No. 6.—*Platinotype Process* (*Willis's. White lines on a black ground*).—This process is based on the reducing action of a ferrous salt, when exposed to actinic light, on metallic chlorides, especially that of platinum.

The sensitizing solution is composed of 60 grains of potassic platinous chloride, 60 grains of ferric oxalate, and 1 oz. of water.

The proper time of exposure is about one-third of that required for the argentic-nitrate process. During the exposure, the initial yellow colour of the sensitized paper becomes pale greyish brown, and finally of a dull orange hue. The last change indicates that the iron salt has been almost completely reduced. If the prints are not immediately developed, they should be preserved from moisture by being placed in cases in which there is a lid containing calcic chloride.

The print should be developed, in non-actinic light, in a solution of 130 grains of potassic oxalate and 1 oz. of water, at a temperature of from 150° to 200° F. The print should be floated in the developing solution for not less than four seconds, with the printed face next to the developing solution. As soon as the print has been properly developed in the above solution, it should be washed, either in 1 part of hydric chloride with 60 parts of water, or in 10 parts of citric acid with 100 parts of water; the hydric chloride solution being the best. The print should be washed in the dilute acid solution for about ten minutes, or until it does not communicate the slightest tinge of colour to the bath; if it does, it should be re-immersed in the bath, or, better still, in a fresh-made dilute acid solution, which should remove all traces of iron salts from the paper. The prints should be finally washed in copious relays of

clean water for at least fifteen minutes. This process is used by the Midland, and London and North-Western Railway Companies, upon the Ordnance Survey, and by the Royal Engineers, and gives most exquisite prints.

No. 7. *Gallic Acid Process* (*Shawcross's direct positive. Black lines on a white ground*).—This process is one of those now employed by the Author; and by giving a direct positive black copy, has a considerable advantage over the other processes described. The reagents employed are inexpensive; and the process is comparatively simple. A gallo-tannate of iron is formed by the combination of gallic or tannic acid with a ferric salt; and this latter salt, on exposure to light, is converted into the ferrous state. The part of the paper preserved from light, not being changed by actinism into the ferrous state, is ready to combine immediately with the gallic acid on immersion in a suitable solvent such as water.

The sensitizing solution consists of 150 parts of gelatine, 60 parts of ferric sulphate, 94 parts of sodic chloride, 18·8 parts of hydrogen tartrate, 150 parts of ferric chloride, and 110 parts of water. The solution should be uniformly spread over the surface of the paper by means of a roller pad, or flat brush (the roller pad being preferable), and the paper dried in the dark. It should then be dusted over with finely-powdered gallic or tannic acid; and the powder should then be thoroughly rubbed on the paper until it is brought into contact with every part of the sensitive surface; it is now ready for use.

As soon as the yellowish colour of the paper is converted into white, the exposure is complete. The lines of the drawing will appear in the initial yellow colour until the print is immersed in the developing bath of water, when the yellow lines will at once be converted into a dark colour approaching to black. If exposed too long, the yellow lines of the drawing will entirely disappear. The prints should be thoroughly washed in two relays of water, the surface of the print being carefully rubbed over with a stiff brush while submerged in the water of the bath. The more thorough the washing, the better is the print; and although the print may appear white after the first washing, subsequent exposure to sunlight will probably show disagreeable discolorations in the white surface. Lines may be altered, or stains removed, by using a 1 per cent. solution of hydric sulphate. When a more rapidly sensitizing solution is required, either glucose or dextrine may be substituted for the gelatine, which will give a violet or purple hue to the reproduced lines on the sun-copy. Blue lines can be produced by substituting potassic ferrocyanide for the

gallic acid; red lines by substituting potassic sulphocyanide for the gallic acid; and green lines with caoutchouc.

The Author strongly recommends the use of this process, which is the invention of Mr. Shawcross, of the Water Engineer's Office, Liverpool; for it does not require an acid solution for development; the exposure may be determined by simple examination; it gives a direct positive, and practically black copy; coloured tracings may be reproduced, as it reproduces half tones; and the copy is in ink (gallo-tannate of iron), and is permanent.

No. 8. *Argentic Nitrate Process* (*White lines on a black ground, or vice versâ*).—This process, although far more expensive than the other processes described, is advantageous when small, intricate, and delicate drawings require to be reproduced.

When organic matter, such as the albumen of albumenized paper, is brought into contact with a soluble salt of silver, a definite compound of argentic albuminate is formed, which on exposure to light becomes dark-coloured. It is inferred, from chemical considerations, that although the dark compound is not argentic oxide, yet the coloration is dependent on the formation of argentic oxide. Argentic albuminate is white, but becomes dark red-brick colour in the presence of actinic light. If gelatine is used as the size instead of albumen, it combines with the silver, and on exposure to light assumes a red tint. If starch is used for the size, exposure to actinic light converts argentic starch compounds into a dark violet colour.

The sensitizing solution consists of 60 grains of argentic nitrate, and 1 oz. of distilled water, with the addition of 10 drops of a saturated solution of citric acid for each ounce of argentic nitrate. This solution should be poured into an earthenware bath for a depth of $\frac{1}{8}$ inch, and is prepared by thoroughly mixing together 154·3 grains (10 grams) of ammonic chloride, 0·264 pint (15 c.cs.) of alcohol, and 2·37 pints (135 c.cs.) of water, and then gradually adding 8 pints (450 c.cs.) of albumen. Its application should be effected as follows:—The paper should be held by the two opposite corners, in such a way that it will first touch the surface of the solution on a line between the two corners not held by the hands. The two corners held in the hands are then dropped, first one and then the other. Any air-bubbles can be removed by gently moving the paper, while half is held out of the solution. If the edges of the paper curl away from the solution, they may be gently blown down to the surface. The paper should be gently drawn from the solution by the adjacent corners, so that it may be drained while it is lifted; and it should then be dried.

A few minutes' exposure in sunlight is sufficient; and when the colour of the print becomes a deep chocolate tint with metallic reflections, it is sufficiently exposed.

After removal from the printing-frame, the print should be thoroughly washed in copious relays of water. The print may be toned in a solution of 1 grain of auric chloride, 30 grains of sodic acetate, and 10 oz. of water; and it should be allowed to remain in this solution for fifteen minutes. After again washing in rain, or distilled water, the print should be immersed in a fixing solution of 4 oz. of sodic hyposulphite and 1 pint of water, for fifteen minutes, and afterwards thoroughly washed in several changes of water, or with a copious supply of water from an india-rubber tube.

No. 9. *Uranium Salt Process* (*Brown or grey lines on a white ground*).—This process is based upon the reduction of uranic nitrate to the uranous state in the presence of organic matter, such as the size contained in the paper, and under exposure to actinic light.

The sensitizing solution consists of 617·2 grains (40 grams) of uranic nitrate, and 4·4 pints (250 c.cs.) of distilled water. The paper should be floated, as in the argentic process, for about eight minutes, in a bath of the above solution, and after drying is ready for use.

The time of exposure required for this paper is rather longer than that required for the argentic process.

If a brown copy is required, the exposed side of the paper is floated for about five minutes, or until the details are completely visible, on a developing solution consisting of 15·43 grains (1 gram) of potassic ferricyanide, 2 drops of hydric nitrate, and 4·4 pints (250 c.cs.) of water; and the print should then be thoroughly washed in slightly acidulated water.

If grey lines are required, the developing solution should be made with 30·86 grains (2 grams) of argentic nitrate, 3 or 4 drops of acetic acid, and 0·54 pint (40 c.cs.) of water. The print should be floated on this solution, when the delineation will rapidly become visible. If the lines are weak, they may be strengthened by adding a few drops of a saturated solution of gallic acid. The print, when fully developed, should be thoroughly washed in pure soft water free from carbonates or chlorides.

No. 10. *Gelatine Process* (*Poitevin's*).—This process is based on the peculiar property possessed by the ferric salt, of rendering gelatine insoluble, so long as it is not exposed to actinic rays.

The sensitizing solution is composed of 10 parts of ferric

chloride, 3 parts of hydrogen tartrate, and 100 parts of water. Before the paper is coated with the sensitizing solution, it should be floated on a 6 per cent. solution of gelatine while this is still warm, and with which is mixed any suitable pigment, of the desired colour, such as lamp-black. When dry, it should be immersed in the sensitizing solution, and afterwards dried; and it is then ready for use. The paper should be sensitized and dried in non-actinic light.

The sensitized paper should be placed behind the tracing, or drawing, reversed as regards right and left. The time of exposure varies from half a minute to several hours, according to the intensity of the light and the thickness of the paper. The gelatine surface which is not covered by the lines of the drawing becomes soluble in hot water on exposure to the light.

After the paper is removed from the printing-frame, it should be immersed in water at a temperature of 80° Fahrenheit, when the soluble gelatine will run off the paper.

No. 11. *Ammonic Bichromate Process* (*Cros and Vergeraud's. Dark brown lines on a white ground*).—The theory of this ingenious process, communicated to the Academy of Sciences,[1] is probably as follows. The action of actinic light converts the bichromate, in the presence of organic matter, into chromium, and renders the organic matter insoluble. The ammonium is dissolved in the solvent; and the chromium, in the presence of argentic nitrate, becomes converted into argentic bichromate.

The sensitizing solution consists of 30·86 grains (2 grams) of ammonic bichromate, 231·48 grains (15 grams) of glucose, and 1,543·2 grains (100 grams) of water.

The time of exposure is similar to that of the Pellet process, and should be continued until the initial yellow colour of the sensitized ground is converted into grey. The print should then be immersed in a solution consisting of 10 parts of acetic acid, 88 parts of water, and 1 part of argentic nitrate. The lines will come out of a red colour, which, on drying, will become converted into dark red.

Printing on Fabrics.—The best description of textile fabrics for this purpose is fine linen, or the finer kinds of cotton fabrics (Nainsook, for example). When silk is used, the denser kinds of sarsanet, and the soft silks are the best.

To albuminize or size the fabric, it should be boiled in water made alkaline by the addition of a little potash, and after drying,

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[1] Comptes Rendus Hebdomadaires des Séances. 1883. Tome 96, p. 254.

it should be coated with a sizing solution composed of 30·86 grains (2 grams) of ammonic chloride, 4·4 pints (250 c. cs.) of water, and the white of two eggs.

The sensitizing operations by the various processes can be performed as for paper, with the exception that, with the argentic nitrate process, 70 grains of argentic nitrate should be used instead of 60. The exposure and developing operations are the same as for paper, with the exception that, with the platinotype process, the acid solution should be composed of 1 part of hydric chloride and 45 parts of water. The Platinotype Company prepares special solutions for the application of the platinotype process to fabrics. If treated with the platinotype solution, the printed fabric can, according to Mr. Willis, be washed when soiled without injury to the image.

Fabrics should be sensitized in non-actinic light, or by gas or lamplight. A good method is to lay the fabric on a glass plate, and apply the sensitizing solution by means of a sponge until the fabric is thoroughly saturated. The material should then be carefully dried, by gently waving it backwards and forwards before a stove until it is quite dry. The fabric should not be brought nearer than 2 feet from the drying-stove, otherwise the sensitizing solution will undergo decomposition. After sensitizing, the fabrics should be preserved from damp.

No. 12. *Zincographic Process.*—This process is used in some of the continental drawing-offices, amongst others, that of the Belgian department of the Ponts et Chaussées. It has this advantage over the other processes described, that when once a zincograph copy has been obtained, any number of duplicates can be reproduced by sending the copy to a lithographic copper-plate printer.

Asphaltum, or bitumen, is the sensitive agent, and was discovered by Niépce de St. Victor. Its application for the production of photographic images was the forerunner of the invention, by his coadjutor Daguerre, of using the iodide of silver as the sensitive agent. Asphaltum, when exposed to light, becomes insoluble to ordinary solvents; so that when it is exposed under a tracing, the opaque lines of the drawing prevent the asphaltum from becoming insoluble. The best asphaltum for this purpose is that obtained from the shores of the Dead Sea in Syria, and is commonly known as Jews' pitch; but it is also obtained from the islands of Cuba and Trinidad. To prepare the asphaltum for use, it should be dissolved in turpentine or benzole, quite free from water; and to this should be added 10 per cent. of oil of lemons. The quantity of asphaltum should not exceed 5 per cent. of the

benzole. Only sufficient solution should be prepared to serve for immediate use; and the sensitizing solution should be prepared in non-actinic light, and allowed to settle. A zinc plate should be used of the same size as the tracing to be reproduced, and should be evenly covered with a film of the sensitizing solution. In order to obtain a perfectly even film, the plates should be placed on a horizontal table or board, which can be quickly turned or spun round by hand. As soon as the sensitizing film is even and uniform, it should be allowed to dry; and if turpentine has been used to dissolve the asphaltum, this will take an hour, or perhaps more. If benzole is used, it will dry far more quickly; and the drying operation can be controlled by the use of oil of lemons, &c.

The tracing, reversed as regards left to right, should be placed in the printing-frame; and the zinc plate should be placed with its sensitized surface next to the tracing, and clamped down or otherwise pressed to it. To prevent the adhesion of the sensitized surface to that of the tracing, the former should be rubbed over with powdered French chalk. The time of exposure varies with the degree of intensity of the light, and the thickness of the asphaltum film; but in sunlight, thirty minutes at least are required, even with the thinnest films. Longer periods, varying from two hours to twenty-four hours, are needed for thicker films. By using an actinograph, similar to the method recommended for the other processes, the progress can be watched. A small piece of zinc, covered with the same solution of as near as possible the same thickness, should be applied under identical conditions. If by rubbing it with a piece of cotton-waste dipped in turpentine or benzole, the cotton becomes discoloured, the exposure is not complete. The edge of the zinc plate can also be tested in the same way.

The plate should be developed by the aid of a ruby lantern. The development is effected by gently rubbing over the sensitized surface with a tuft of cotton dipped in olive oil. After the expiration of a few minutes, it should be gently rubbed over with turpentine. The image will gradually appear; and the alternate process of rubbing with oil and turpentine should be continued until the soluble parts are cleared. The plate should then be washed with soap and water, and finally washed in a copious supply of clean water, and then dried, after absorbing the water with blotting-paper.

Another method consists in filling a bath with turpentine, and immersing the plate therein, gently rocking the plate until the

soluble parts of the asphaltum are washed off; but care must be taken not to allow the turpentine to dissolve the parts which should be insoluble. The plate should be finally rinsed with clean turpentine, and then washed with water until the soluble parts are cleared off, and lastly dried. This immersion operation requires more care than the rubbing method, but it is more rapid. A solution of nitric acid, made by adding to it twice its volume of water, should then be applied, either with a quill or a tuft of cotton-waste, to the exposed parts of the zinc plate, until it is sufficiently etched for printing by a copper-plate printer.

In the preparation of asphaltum it is found that a greater degree of sensitiveness and sharpness of definition is effected by adopting the following process. The asphaltum is dissolved in rectified oil of turpentine until the solution attains a syrupy consistency. After resting a few days, ether is added to the solution to the extent of three to four volumes, and two days subsequently the resulting precipitate is removed and washed with ether and dried; it is then redissolved in pure benzole, to which 1·5 per cent. of Venice turpentine is added to produce a more flexible coating, and it is then ready for use. The exposure and the development are the same as for the asphaltum prepared in the ordinary manner.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been prepared.

(*Paper No. 2183.*)

"Demolition of the North-East Wall of the Gallions Basin, Royal Albert Docks, on the 23rd of April, 1886."

By Col. Benjamin Hay Martindale, C.B., Assoc. Inst. C.E.

In 1883 the directors of the London and St. Katharine Docks Company decided to construct a second entrance from the Thames into the Gallions basin. The Bill giving the necessary powers received the Royal Assent on the 12th of May, 1884. The works were then taken in hand, and it is not intended in this Paper to give any account of them. At some future time, perhaps, an opportunity may be sought to lay a brief statement of any points of interest before the Institution. Here, it is only necessary to say that the works consist of a new entrance, with a wharf stretching from it 1,120 feet down the Thames, and of an extension of the existing basin, Plate 10, Fig. 1; and that in order to connect the new with the old part of the basin, and to give access from the new entrance into the basin and so into the Royal Victoria and Albert Docks, the wall shown on plan had to be removed.

This wall was 520 feet long, and, like the rest of that surrounding the basin, was 38 feet deep, 19 feet wide at the bottom, and 5 feet wide at the top. The face had a batter of 1 in 27 for 25 feet, then of 1 in 6 for 6 feet, and then sloped forward for 3 feet at an angle of 45°, with an apron 14 feet wide and 6 feet deep. The back of the wall was thickened by four steps; the first 2 feet wide, and 3 feet from the top; the next two steps, each 2 feet 4 inches wide, and 7 feet deep; the last, 2 feet 4 inches wide, but only 3 feet 6 inches below the third step. The wall was then straight to the bottom, Fig. 2. It was made of concrete composed of 6 parts gravel and 1 part Portland cement, and was of great hardness and strength. The water, at Trinity high-water, was 6 feet below the top of the wall; the ground was level with it behind, and formed the quay. At 40 feet from the edge stood a corrugated-iron warehouse, 264 feet long by 60 feet wide, the roof supported on piles, and having railway lines in front and rear, Fig. 2. This warehouse, being in the way, was removed at an early period of the works, but the piles were left which had supported the roof in front.

The Gallions basin was incessantly in use, the largest steamers trading to the Port of London—such as the Peninsular and Oriental, the British India, and similar lines—passing close to the south end of the wall when being docked and undocked, the entrance to the lock being within 130 feet of this end. The loading-berth of the Orient line adjoined the north-west end of the wall; at the other side of the basin were two loading-berths for similar steamers, and craft in large numbers were constantly present. The inner lock-gates of the existing lock and of the new lock were within 180 feet. The office and stores of the Orient line, a two-storied corrugated-iron building, were within 70 feet of the north-west end, the Gallions Railway Station within 160 feet, and the Gallions Hotel within 260 feet. Adjoining the office and stores was a corrugated-iron warehouse, 264 feet long, and 60 feet wide, lighted by a skylight extending the whole length of the roof; a large pumping-station was about 450 feet distant; and the dock-masters houses about 630 feet. Two corrugated-iron sheds, of similar dimensions to that above named, were about 500 feet off, on the side of the basin opposite to the wall, and there were other minor buildings in the vicinity.

The problem was, effectually to crumble away the wall without any interruption to the dock business, without damage to the adjacent premises, and without injury to those employed at the docks, or to the public.

The directors had entrusted the execution of the works to Mr. Robert Carr, M. Inst. C.E., the Company's Engineer, and Mr. Joseph Thomas, the Company's Assistant-Engineer, with the supervision of the Author. When the time arrived to consider how best to remove the wall, several conferences were held, and the result was the following plan, the main burden of carrying it out falling on Mr. Thomas, by whom most of the following details have been supplied:—

A line of timber sheet-piling, 14 inches square, was driven about 4 feet from the back of the bottom of the wall, thus revetting the earth from quay level to the bottom of the wall, and forming a sort of inner dam. A second row of piles was driven about 24 feet in rear of the sheet-piling, but 12 feet apart, the piles which had supported the roof of the warehouse at 24 feet apart coming here again into use. A line of waling was fixed near the top and along the front of the sheet-piling, and another line of waling along the back of the rear piles, and the whole was tied together by tie-rods 2 inches in diameter with 9 inches cast-iron washers (Plate 10, Figs. 3 and 4).

As soon as a sufficient part of the revetment had been completed, the excavation of the earth between the wall and the revetment was commenced, and gradually extended until men were at work along the whole length of the wall. Simultaneously with the excavation of the earth, the off-sets of the wall were cut away perpendicularly, till it stood throughout its entire length and depth at a mean thickness of about 6 feet (Plate 10, Fig. 3). The first off-set was removed by charges of about ½ lb. of powder each, in holes about 2 feet deep. Subsequently such charges were employed as sufficed just to break the off-sets away, the fragments varying from 2 tons downwards, the average being about 1 ton. These charges were placed in holes bored perpendicularly in the off-sets, from 2 to 5 feet in depth, and from 1½ inch to 3 inches in diameter. The charges varied from ½ lb. to 1½ lb. of powder or compressed cartridge; the dynamite was used in ½ lb. charges. About seven to nine charges were fired at one time. Warnings were given by bugle calls before any charges were fired.

For thinning the wall as above stated, the number of holes drilled was three thousand one hundred and twenty-seven, of a total length of 11,765 feet. The explosives used in these holes consisted of 1,900 lbs. of J. Hall and Son's pebble powder, L. G. B., 1,050 lbs. of J. Hall and Son's patent compressed powder cartridges, and 105 lbs. of Nobel's patent gelatine dynamite. The fuze employed was Bickford, Smith and Co.'s patent gutta percha fuze, No. 13. The powder and compressed cartridges were used in preference to dynamite, as being less likely to shake the part of the wall which it was desired to leave intact until the end, except where the holes were wet, and for the purpose of trying the effect of the dynamite on this wall.

The drainage of the space between the wall and the revetment was very effectually maintained as follows:—A sump was formed at each end of the wall, and at the bottom of each sump a 15-inch iron pipe was connected with the 15-inch earthenware pipe which carried the water from the works to the main sump. Each pipe was fitted with a 15-inch valve, so that in the event of any in-rush of water from the basin these valves could be closed, and the water cut off from the works.

Protecting piles were driven 14 feet in front of the wall in the basin, with a waling running from end to end to prevent craft striking against the wall as the work progressed. As the excavation proceeded, lines of waling were run along the back of the wall, and five rows of struts were placed from these to corresponding walings in front of the revetment. These struts were 9 feet 3 inch

apart, and extended over the whole length and depth of the wall (Plate 10, Fig. 3). They assisted the wall to withstand the pressure of the water in the basin, as the tie-rods helped the revetment to resist the earth-pressure. The whole system stood admirably, but the struts had to be carefully watched, and at one time some of the upper ones had to be removed, as there were indications of too great pressure against the top of the wall from the earth. It was found by careful theodolite observations that variations in the weather sensibly affected the ground and struts, so much so, that the revetment sometimes gave as much as 2½ inches near the top, and the wall in the centre moved in response to it.

A considerable quantity of water came through slight cracks in the wall, and increased or decreased with any movement in it. But this percolation was easily kept back by the following means:—A small box filled with stable manure, breeze, and sawdust, and fitted with a sliding cover, to which a lever was fixed, was let down into the water over the face of the crack. As the cover was removed, the mixture filled the crack, and so stopped the water.

The arrangements for the final demolition of the wall were as follow (Fig. 5):—Holes were first drilled vertically into the centre of the coping about 3 feet deep, and then as the thinning of the wall progressed holes were drilled in the back of it, partly by hand and partly by Ingersoll rock drills. These holes were 4 feet apart, and placed alternately beneath one another. They were driven at an angle of 45° towards the water, with the object of throwing the wall in the first instance forward, as it measured in front about 525 feet, and in the back about 515 feet only, and it was desired to avoid anything like a jam at either end. To ensure the wall being broken off tolerably straight at the ends, it was pierced to within 1 foot of the face by holes drilled down the back at intervals of about a foot apart, so that the rear of the wall to be demolished resembled at each end a magnified postage stamp. These holes were not charged. The number of holes drilled for the final demolition was one thousand four hundred and fifty, of a total length of 6,381 feet. This, added to the length already stated, gives a total length of holes drilled of 3 miles 34 chains 62 feet, approximating to 4 miles.

The explosive used was Nobel's patent gelatine dynamite; the quantity employed was about 2,900 lbs., in charges of from ½ lb. to 3 lbs., with one row of 6 lbs. The fuzes were Sir Frederick Abel's high-tension electric fuzes, supplied by Messrs. Powell of Plumstead, of an average resistance of 3,000 ohms. Each fuze was carefully tested before being used.

The following arrangements were adopted in charging the holes:—As considerable apprehension existed that some of the gelatine dynamite, which freezes at 40° Fahrenheit, might be frozen, as indeed proved to be the case, warming-pans were provided, and great care was taken to render the dynamite pliable and fit for loading the holes. One of Abel's high-tension electric fuzes, with a detonator containing 10 grams of fulminate of mercury, was soldered to two 10-feet lengths of insulated copper wire, which passed through two perforations in an india-rubber bung, the bung being fastened close to the head of the fuze by the wires being cemented in with Chatterton's cement. A waterproof bag containing a cartridge of about 1½ oz. of gelatine dynamite having been prepared as a primer, and a hole made in the gelatine by a "former" for the reception of the fuze, the bung with the fuze attached was then fitted into the waterproof bag, the mouth of the bag and the bung having previously been smeared with india-rubber cement to render the whole waterproof. Each hole, as it was charged, was carefully tamped with dried clay.

The 6-lb. charges were used to overcome the batter of the wall, and also to counteract in part the direct action of the 3-lb. charges above them, and to tilt the wall forward. To assist the force of the explosion, water was let into the ditch at the back of the wall to a depth of 10 feet, but not deeper, for several reasons, among others, that the pressure of the water in the basin was wanted to force the wall, as it fell, against the revetment, and so prevent its spreading into the basin and hindering the navigation. Mr. Toye, one of Messrs. Nobel's inspectors, was employed to superintend the warming of the dynamite and charging and tamping of the holes, and performed this duty very efficiently.

The arrangements for simultaneously exploding the charges were as follow:—The Royal Albert Docks are lighted throughout by electricity distributed from four stations, one of which was within 300 yards of the wall. From this two well-insulated main leads of copper wire were brought into the basin; these, at a point about 75 feet from the wall, branched into six leads, which were connected at each end and in the centre of the wall with the network of wires attached to the fuzes, thus making three distinct connections. This network again was connected in compound series, with about twenty fuzes in a series, connecting the lines of holes perpendicularly, and so duplicated that, in the event of one series failing through a faulty fuze, it would derive its current from the next series, thus preventing the possibility of a whole series missing fire through having a faulty fuze in it

(Plate 10, Fig. 6). The necessary force was provided by one of Siemens alternating-current machines, used for lighting the docks, and giving about 1,200 volts and 16 amperes. The amount of wire in the leads exceeded a mile, with about 6 miles of branch wire, involving about three thousand joints. Every joint was carefully insulated, as three rows of holes were under water at the time of the explosion. The two leads into the basin were connected near the Manor Way bridge, about 570 feet from the wall, with a tumbler-switch or firing-key, which, by pressure upon a button, completed the circuit and fired the charges. The wire for the leads and network was supplied by Messrs. Siemens Bros., by whose representatives, Messrs. Barnes and Kingston, everything connected with this important part of the work was most effectually carried out. The charges were fired by Mr. Albert G. Sandeman, Chairman of the London and St. Katharine Docks Company, at ten minutes past six A.M., on Good Friday, the 23rd of April, 1886. This time was specially selected to minimize the chance of injury to those employed in the docks or to the public, to avoid interruption to the dock traffic, and to infringe as little as possible upon the day. It also gave time to search the basin to see whether any fragments of the wall might lie in the way of shipping.

The explosion produced exactly the intended effect, as the wall crumbled in a heap into the vacant space in its rear, and into the water immediately in its front, none of it projecting more than 35 feet beyond its base (Plate 10, Fig. 4). No interruption took place to the dock business. Two large ocean-going steamers were undocked from the basin at 4.30 A.M., and at 6.10 A.M., as already stated, the charges were fired, and from the reports of the divers, who descended immediately after the explosion, it was evident that the ordinary work of the dock might have been at once resumed. It was resumed the first thing on Saturday morning, Good Friday being a dock holiday. No injury occurred to person or property—not even a window in the Orient store and office, the nearest adjacent building, was cracked. Very little vibration was perceptible, and the report was not louder than the quick firing of two or three Gardner guns, the sound of which it much resembled. Some light boards, used to prevent persons trespassing on the works, were blown from 20 to 30 feet vertically into the air, with a cloud of smoke, dust, spray, and small débris, along the whole length of the wall. A small wave was raised in the basin, perhaps 2 feet high, which was expended before it reached the opposite side. Out of four dummies, made from divers' dresses stuffed with straw, and placed on the ground about 35 feet behind

the face of the wall, three remained unmoved. The centre one was knocked over by a block of the concrete coping, some large fragments of which lay perilously near the others also.

After the explosion, sections were taken by careful soundings, and it will be seen from Fig. 4 within how limited an area the wall fell. The fragments vary from 3 tons downwards; the majority are about 1 ton. The large fragments are from the concrete coping. The action of the 6-lb. charges appears to have been to reduce the concrete to small stuff, capable of being easily dredged by ordinary dredging.

The Author was strongly and persistently urged to fill in the space between the wall and the revetment with water, and to remove the upper part of the wall, so as to place the remainder also under water, and very dismal prognostications were uttered as to what would happen if the wall was demolished in the way adopted.

The theory adopted was that the wall would move at first slightly towards the basin, and then be forced by the water into the vacant space between it and the revetment, and this exactly took place, the whole power of the dynamite being absorbed, as it was calculated it would be, in doing the work it was intended to do.

The Paper is illustrated by several tracings and photographs, from which Plate 10 has been prepared.

(*Paper No. 2161.*)

"The Bilbao Ironworks."

By Neil Kennedy, M. Inst. C.E.

It is beyond the scope of this communication to enter upon a notice of the antiquity of the iron industry which has made Spain well known all over Europe. It will suffice to mention that during several centuries Vizcaya, the province of which Bilbao is the capital, was the centre of a comparatively large commerce in fine qualities of iron, principally destined to warlike and agricultural uses. In those olden times, when this part of Spain was to all intents an independent republic, its laws were strongly protective, and the penalty of death was imposed upon the person who exported, or who attempted to export, the fine soft ore now so well known to all European ironmasters. At the present time Bilbao supplies a large percentage, it is believed nearly one-sixth, of the iron ore used in the United Kingdom, and many of the principal works would be paralyzed to-morrow if this supply were stopped. Mr. William Gill, M. Inst. C.E., presented, in 1882, to the Iron and Steel Institute, such an exhaustive report on the iron-ore mining- and transport-industries of the Bilbao district that nothing is left to be said on that head.[1]

The river-improvements have been such an important factor in the question of establishing ironworks, that a slight notice of these is imperative. Before they were commenced, the establishment of ironworks in Bilbao on an important scale was simply out of the question, as the uncertainty of the passage of the bar at the mouth of the river was such that the reserve stocks of coke necessary to meet the various contingencies would have represented a standing capital producing nothing but waste, and would have swamped any ordinary concern in a very short period. The measure of river improvements is the commercial result they give to the shipping interests, and looking at the Bilbao river from this standpoint, the following is what has been obtained. In 1879 the largest cargo which crossed the bar was 1,658 tons of iron-ore, on a draught of $15\frac{10}{12}$ feet. In 1884 the largest cargo was 3,219 tons on $20\frac{10}{12}$ feet, or an increase of 1,561 tons burthen and 5 feet

[1] The Journal of the Iron and Steel Institute, 1882, p. 63.

draught. In 1879 all traffic over the bar was stopped for weeks, and even months, at a time; whilst in 1884 and 1885 the time lost to ships for the same reason could be counted in days. Such a result as this, in five years, is a great credit to the Harbour Board and to their engineer.

It will now be understood why the establishment of modern ironworks has been so long delayed in the Bilbao district. It is a curious coincidence that whilst nearly all the capital invested in the mining undertakings is foreign, yet the whole of that laid out for manufacturing purposes is Spanish.

Before proceeding to describe the modern works, it may not be out of place to mention that one of the ancient methods of making iron was that known as the Catalan forge process, by which malleable iron is manufactured direct from the ore, without the intermediary casting. Some of the old works are still in operation where ore is cheaply obtained, and where water and charcoal are abundant. Mr. J. A. Phillips, M. Inst. C.E., in his text-book on metallurgy, gives an excellent description of one of these relics of ancient practice. Although this art is being lost so rapidly that in a few years it will probably have become unknown, and ought long ago to have become extinct on account of its wastefulness, yet one can hardly see work going on in these dreary weird old forges without recalling the times when Englishmen made use of their produce with avidity, and in more ways than one.[1]

To understand the excellent quality of the ore produced in this district, the following statement will probably be more intelligible, and certainly be more interesting to most people, than a complicated chemical demonstration. Mr. Philip Sewell, M. Inst. C.E., has told the Author that about thirty years ago a Basque smith, in his presence, made a piece of malleable-iron direct from a lump of roasted ore. Mr. Sewell still has in his possession the piece of iron then made in a simple little hearth, with the ordinary charcoal fire of the country, and with a wretched bellows.

Possessing in abundance a superior quality of iron-ore and limestone, and now being able regularly to import the best English coke at reasonable prices, the people of Bilbao have not been long in endeavouring to make use of these advantages. The following three first-rate establishments are now hard at work making hæmatite pig-iron, one of them even making steel rails.

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[1] Pistol's sword, Merry Wives of Windsor, Act I., Scene 1, and the instrument of torture, Hamlet, Act V., Scene 2, undoubtedly received their names from the place in which the iron of which they were made was manufactured.

Vizcaya Company.

This company possesses two blast-furnaces, designed and erected by Messrs. Cockerill, of Seraing, Belgium. Both were put in blast during 1885. They are 67 feet high, 6½ feet in diameter in the crucible, 19¾ feet in diameter in the boshes, and 16 feet in diameter at the top. The blast enters through four tuyeres, after being heated by Whitwell stoves to 1,300° Fahrenheit. These stoves are 40 feet high and 20 feet in diameter, and there are six of them to each furnace. The gas is withdrawn through the bell by means of a sliding arrangement, which looks clumsy, but may be effective. It is utilized for producing steam and heating the stoves in the usual way. The blast-engines are of the vertical type, Seraing No. 3, and are condensing, as salt water has to be used in the absence of a sufficient quantity of fresh. The pressure of the blast is about 5 to 5½ lbs. per square inch.

The production of pig-iron is at present about 600 tons per week per furnace, on a consumption of about 18 cwt. of coke per ton of iron. This company intend to lay down a Siemens-Martin steel plant whenever their furnace-business has settled down quietly. Their furnaces have been raised above ground-level, so as to enable the conduction of the molten metal to the converters in a suitable ladle.

San Francisco Works.

At these works, the property of the Marquis of Mudela, there are four furnaces, which were designed by Mr. F. Stephens. They commenced work in 1882. They are 56 feet high, 6½ feet in diameter in the crucible, and 16½ feet in diameter in the boshes. The gases are taken off and utilized in the usual way. The blast is heated to a temperature of 1,200° Fahrenheit by means of thirteen Whitwell stoves, all communicating into one main tube. The stoves are 25 feet high, and 12 feet in diameter. One of the blast-engines is vertical, and the other is of the beam type. The production of each furnace is at the present time about 300 tons of pig-iron per week, with a consumption of 19 to 20 cwt. of coke per ton. The coke, after being discharged from the steamers, is carried by wire ropeways to large bunkers, out of which it runs automatically into the feeding-barrows.

Altos Hornos Company.

This company was started to take over and transform older works belonging to Messrs. Ibarra. The antiquated blast-furnaces

were abandoned, and two new ones, of the ordinary Middlesborough type, have been erected and brought into blast during 1885. They are 80 feet high, 9 feet in diameter in the crucible, 16½ feet in diameter in the boshes, and 14½ feet in diameter at the top. Each furnace has eight tuyeres, and the blast is heated by means of Cowper stoves, two to each furnace. These stoves, about 70 feet high and 20 feet in diameter, are capable of raising the blast to a temperature of 1,300° Fahrenheit. The gases are withdrawn through two side openings at the level of the bell, and are used for heating the blast and raising steam in the whole establishment, without the necessity of coal, when the furnaces are working well. The blast-engines are of the vertical type. The production of pig-iron is about 600 tons per week per furnace, and the consumption of coke is from 17 to 18 cwt. per ton of pig. Near these furnaces are two 9-ton Bessemer converters, room being left for a third. There are three Spiegel cupolas.

The rail-mill in connection with the above plant was started in January. The engine of this mill is said to be one of the largest, if not the largest, ever laid down for this purpose, and develops 8,000 HP. There is a roughing-mill, a 39-inch blooming-mill, a 30-inch rail finishing-mill, for turning out rails of the heaviest sections in use, and in lengths of 180 feet, and a bloom shearing-machine capable of shearing steel blooms 1 foot square. All this plant, that is, the Bessemer converters, cranes, rail-mills, &c., has been supplied and erected by the best English manufacturers, and is of the most modern and most approved style. Mr. E. W. Richards, M. Inst. C.E., supplied the designs.

This company also carries on a lucrative business in the manufacture of ordinary commercial iron, utilizing for this purpose the old rolling-mills, somewhat improved and added to.

Besides these three principal establishments of which a short notice has been given, there are spread through the country small works whose produce is insignificant, and which are now dedicating themselves to work up the pig made in the more important smelting-furnaces.

From what has been said it will be seen that at the present day the manufacture of hæmatite pig-iron is carried on in Bilbao at the rate of about 180,000 tons per annum, and that a very powerful steel-rail manufactory has been started this year. In December last this rail-mill secured an order for 12,000 tons of steel rails, to be delivered in Spanish Mediterranean ports at the price of 141 pesetas per ton (say £5 8*s.* at present exchange), which was 12 pesetas, or 2*s.* 6*d.* below the tenders of twenty English, Belgian,

and German manufacturers. It must be understood that there is an import duty in Spain on foreign rails; but, notwithstanding, the result is simply this, that the Spanish market is practically lost to outsiders, and if prices ever go up an amount equal to these import duties, Bilbao rails can compete well all over the world, as freights from Bilbao are now extremely favourable on account of the river improvements already mentioned. It will be seen that the quality of the rails is the same as those of English make, because, as shown, the same machinery, the same ores, and the same combustibles are to all intents used.

The hæmatite pig-iron produced will also be easily disposed of, as its quality is first-class, and its production could no doubt be raised to 250,000 tons per annum with the present plant. The price of making pig is not very easily arrived at with accuracy, as of course the companies are not willing to publish these secrets to the general public; but it is thought that very little is put on board ship which does not cost 37*s.* 6*d.* per ton. This price does not leave much margin in the present depressing times, but yet sales are regularly being made, and probably English makers of good brands find more difficulties in disposing of their produce than their Bilbao *confrères*, although these latter are fresh in the competition.

It will always be interesting to watch the ultimate success or failure of these new undertakings, in which 1 ton of coke is taken from England to Spain to obtain the same results, and to compete with 2 tons of iron ore taken from Spain to England.

(*Paper No. 2192.*)

"Experiments on the Steam-Engine Indicator."

By Professor Dr. KIRSCH, of Chemnitz.

THE corrections for the various errors adopted by Professor Osborne Reynolds in his Paper "On the Theory of the Indicator, and the Errors in Indicator-Diagrams,"[1] having attracted the attention of Dr. Berndt, of Chemnitz, who has been working in the same direction, the Author made the following observations with a view to bring the results of these two experimenters into accord.

In the experimental engine, $p = 4 \cdot 5$ atmospheres (66·15 lbs. per square inch), the cut-off ratio is E, the mean back-pressure 0·21 atmosphere (3·087 lbs. per square inch), the clearance-space 5 per cent. of the cylinder-volume; then the work done by the steam is proportional to the values—

$A_i =$	1·554	2·304	2·770	3·306	3·640
For E =	0·1	0·2	0·3	0·4	0·5

If in consequence of the drum-friction the paper-cylinder remains stationary for a short time at every change of stroke, so that, for instance, the diagram is shortened by 2, 4, 6 per cent. of its length, the area of the diagrams will be less than the above figures represent, and in place of the latter are obtained—

For 2 per cent. pause	1·468	2·218	2·684	3·220	3·554
„ 4 „ „	1·382	2·134	2·598	3·134	3·468
„ 6 „ „	1·296	2·046	2·512	3·048	3·382

When running without a load the engine works with wire-drawn steam of 1·2 atmosphere (17·64 lbs. per square inch) pressure and a cut-off 0·1, which gives as corresponding factor for the work done the value $A_o = 0 \cdot 260$.

If, however, the drum remains stationary at the change of stroke, the area of this diagram will also be less, and becomes for 2 per cent. 0·240; for 4 per cent. 0·220; for 6 per cent. 0·201.

[1] Minutes of Proceedings Inst. C.E. vol. lxxxiii. p. 1.

The actual difference between indicated work with, and indicated work without, a load, is therefore—

For	$E = 0\cdot1$	$0\cdot2$	$0\cdot3$	$0\cdot4$	$0\cdot5$
$A_i - A_o$	$= 1\cdot294$	$2\cdot044$	$2\cdot510$	$3\cdot046$	$3\cdot380$

and if it be assumed that the additional friction is in reality 13 per cent. of the effective work, the following proportional values are obtained for the actual effective work,

For	$E = 0\cdot1$	$0\cdot2$	$0\cdot3$	$0\cdot4$	$0\cdot5$
	$A_e = 1\cdot145$	$1\cdot809$	$2\cdot221$	$2\cdot696$	$2\cdot991$

If it be now assumed that the drum is retarded for a portion of the stroke at every change of the latter, there follow, with the help of the above apparent indicated work and also the apparent work without a load, the differences—

For 2 per cent. pause	1·228	1·978	2·444	2·980	3·314
„ 4 „ „	1·162	1·912	2·378	2·914	3·248
„ 6 „ „	1·095	1·845	2·311	2·847	3·181

If these values, taken from the false diagrams, of the apparent differences $A_i - A_o$ are compared with the above correct values of the effective work, the amount by which the apparent $A_i - A_o$ is greater than the correct A_e will be found to be no longer of course exactly 13 per cent. but respectively—

For 2 per cent. pause	+7·3	+9·3	+10·0	+10·5	+10·8	per cent.
„ 4 „ „	+1·5	+5·7	+ 7·0	+ 8·1	+ 8·6	„
„ 6 „ „	−4·4	+2·0	+ 4·0	+ 5·6	+ 6·3	„

This would explain in a very simple manner why the additional friction, with a very high degree of expansion, may even have an apparently negative value, a fact which has actually been frequently observed by Professor Berndt.

(*Paper No. 2,199.*)

"Note on the Gold-fields of South Africa."

By Sidney Howard Farrar.

The Gold-fields visited by the Author include those at Pilgrims Rest, N.E. of Lydenburg; Lydenburg, E. of Lydenburg; De Kaap, S.E. of Lydenburg; and Witte Water Rand, situated about 30 miles S.W. of Pretoria, and only recently discovered.

In addition to these, fields have been opened since March 1886 close to Griqua Town, and in the Hoogeberg, a short distance from the port of Knysna. These two latter fields are, however, as yet not sufficiently developed to justify any comments. At the De Kaap Fields (and these remarks apply to Nos. 1 and 2 also) timber is a luxury, and the water-supply, though fairly good, will not be sufficient to provide power for any large development of these fields, which is going on by leaps and bounds. Large coal-beds, however, exist within 60 miles of the De Kaap Fields, and in the opening up of these coal-beds, and the laying down of lines of communication, there will undoubtedly be a good deal of work for engineers. Then again, it is quite certain that in a short time these fields will be of such importance, that a railway will be constructed either to meet the Natal system at Estcourt, or, more probably, to join the line about to be constructed from Delagoa Bay to Pretoria. At present the water-power existing on these fields is the sole means of working the machinery. It is difficult to over-rate their future importance. People there are keeping matters very quiet; but in a few months there will be a large influx of population, and probably work for engineers.

The De Kaap Fields (the most promising), are reached from Natal in about six days. There is a good weekly post-cart service from Estcourt, where the rail ends, and the cost of the journey from Durban to De Kaap, including living expenses, is about £30.

The climate is healthy, except from March to May when fever is rife, but this may be avoided by keeping to the high ground. As to the richness of these fields, on one property which was opened up about eighteen months ago, gold has been found to the value of £2,000 per month, the working expenses being £900.

The average yield of the De Kaap Fields is from $2\frac{1}{2}$ to $1\frac{3}{4}$ oz. per ton.

A large Company has been formed in the Colony to work claims on Moodie's Reef, and plans for the machinery are now being prepared. As water is scarce, full advantage has been taken of the available fall, 750 feet, which renders the question of the motor supply-pipes a serious one. These will be of wrought-iron. The motor proposed to be used is a Californian wheel, which is thought in such cases to be preferable to a tangential turbine. The quartz has to be conveyed some distance to the machine site, and the present claim-holders, who are working in a primitive manner, take it down in bags. A wire ropeway has been arranged with two fixed ropes, and the buckets working by gravitation. The span will be 900 yards, and the fall about 300. In some specimens furnished by the Author the quartz weighed 17 oz., and the gold $58\frac{1}{2}$ grains, showing a yield of 230 oz. per ton. The average yield of the claims belonging to the Company referred to is 3 oz., but the yield is estimated at 1·75 oz., because at present the people are only crushing picked lumps of quartz. With good machinery, by crushing quartz which is now wasted, the yield per ton will be less, but the gold gained will be more.

At Bray's Quarry, near Moodie's Reef, 7 oz. per ton have been obtained. The Author anticipated this result, as the quartz is very rich; but as it will have to be carted 7 miles in order to bring the battery within reach of water-power, the working expenses will be very high. The only chance of economical power is to erect turbines alongside a small river which runs past the quarry, distant about 6 or 7 miles, and which has a considerable fall.

A Company has recently been formed to work the "Sheba Reef," in the De Kaap Fields, with a capital of £12,000. The first clear-up has now taken place, and 400 tons of quartz have yielded £8,000 of gold (at 71*s.* per oz.), with the result that one thousand £1 shares in the Company changed hands at £14 each, and shortly after an offer of £25,000 was made for them. The expenses attendant on working this reef are heavy, but it is stated that a tram-line is being laid down to convey the quartz to the Crocodile River, 7 miles distant, where, as anticipated, turbines are to be erected for working the necessary batteries, &c. There is some talk of working the coal-beds known to exist some 60 miles off; so these fields promise well for engineers. The strike of the reef is mostly east and west, and the dip mainly vertical. The geological features of the country have been so fully described that it is unnecessary to go into the question.

At present (June 1886) there are about two hundred diggers on the Knysna Fields; but as they have not got down to the older alluvial beds yet, it is difficult to form any opinion. The results, so far, are poor, but there are indications of reefs, and the yields improve in the alluvial the deeper the diggers get.

All the Companies at De Kaap are doing well, excepting one, which appears to have got into the leg of a "saddle" reef which it has worked out, leaving the real paying portion to its neighbours.

The reports from the Knysna Gold-fields are of a promising nature, and as diggers get down into the alluvial soil the yields, as was anticipated, are improving. Nuggets of from ½ to 1 oz. are being found, and, contrary to expectation, these fields bid fair to turn out a "poor man's" diggings. The country is well timbered, with abundance of water. Prospecting is difficult and expensive, as the alluvial soil is covered with a rich black loam, thickly wooded. As these fields are close to the port of Mossel Bay and equally near to a fine natural harbour (Knysna), they bid fair to take a leading position among South African gold-fields. It is too early yet for sanguine views to be justified, but the indications are good, and lately good discoveries have been made. It appears evident that a very large tract of country in the Mossel Bay district is more or less auriferous. There are five hundred to seven hundred diggers there already; but as few of them had any idea how to work, up till lately but little good has been done. A few experienced men have however gone down, and as the others have gained experience, matters have gradually improved. It is proved beyond doubt that men willing and able to work can pay expenses there easily. Companies are in course of formation to work various claims by "hydraulicking;" but this system requires large capital and very careful preliminary investigation, so it will be some time before much is done in this direction. A "Ball" (Bazin) dredger has been worked in the attempt to discover gold in the beds of the rivers, but the presence of large boulders prevented its successful operation, and the experiment has been temporarily abandoned.

The Paper is accompanied by a large map of South Africa, published by J. C. Juta and Co., of Cape Town, in 1885, and specimens of auriferous quartz from the De Kaap Gold-fields.

OBITUARY.

Sir JOHN ANDERSON, who died on the 28th of July, 1886, was elected a Member of the Institution on the 4th of February, 1862. His career was one well calculated to encourage young engineers, as it affords an instance of steady success attained by a clear brain with determined concentration of mind on the matter in hand. Sir John had so worn himself out in the service of his country that, for many years before his death, he had been compelled to seek the rest and quiet which his health imperatively demanded; and thus it happened that his name was latterly less before the public than was once the case.

Born at Woodside, near Aberdeen, on the 9th of December, 1814, three months after the death of his father, he was known when very young by his genial spirits and affectionate nature, as well as by the vigour with which he threw himself into all the amusements of the boys of the village, among whom indeed he generally acted as a leader. He received at the village school the usual good education which has long been the advantage possessed by children of every rank in Scotland. When at home he was carefully looked after by his mother, a woman of a remarkably affectionate nature, and also by his stepfather, Mr. Irvine Kempt, a man held in high esteem in the neighbourhood for extreme uprightness of character, as well as for being possessed of an extensive general knowledge far above the average. It was probably from the influence which he exercised on the young boy that he, like his stepfather, developed a taste for reading and a great desire to acquire knowledge. This love for books induced him at a very early period to become the honorary librarian of the church library at Woodside, and people who were readers then, and have now grown old, relate how pleased and able the librarian was to advise them as to the books they should select. Sir John Anderson seems never to have forgotten this part of his youthful experience, for towards the end of his life, actuated by the desire that the youth of his native village should cultivate a habit of reading from which he himself had drawn so much pleasure and advantage, he erected at Woodside a free library, well stocked with the best literature of the day, every volume of which had been specially selected by himself.

Near to Woodside, which stands on the banks of the River Don,

were large cotton-mills, and in these Mr. Kempt held a responsible position as Manager of the engineering-shops. It was through his influence that his stepson was taken into these mills, first as a boy clerk, and afterwards to serve an apprenticeship of seven years as an artizan in the shops. In these workshops the young lad was under the same kind and intellectual eye as in his home, and he rapidly grew to be an excellent workman. From the first he took great interest in machinery. While an apprentice, in his spare hours, among other things he made for one of his friends a wooden clock which kept good time, and to another he presented a lathe of his own manufacture. But he did not occupy all his spare time in these amusements; regularly in the evenings he walked into the city of Aberdeen, 2 miles distant, to attend at the Mechanics Institute the classes for mechanical drawing and other subjects. He was also at this time the centre of a small number of kindred spirits about his own age, who met in the evening to discuss chemical and scientific questions, and to solve, as best they could, difficulties with which they had no better means of grappling. As the term of his apprenticeship drew to an end, he resolved that there was at Woodside no sufficient scope for a career, and he determined to go south, so that he might become thoroughly acquainted with the best mechanism, and the modes of executing work in the first workshops of the kingdom, and obtain, if he could, a situation which would give him a favourable opening. At the age of twenty-five years, on the day his apprenticeship ended, he left Woodside for Manchester, and went to work with Messrs. Fairbairn, a firm to which he had been recommended by his stepfather. He did not, however, remain there many months, but having seen what he wanted, he left and worked in succession with Messrs. Sharpe Roberts and Co., Manchester, Messrs. Penn of Greenwich, and Mr. Napier of London. During this period, which lasted from 1839 to 1842, the young man was storing his mind with a complete knowledge of the various metals, and their best treatment under various circumstances. He was not, however, without anxiety as to his future. The state of trade was at the time particularly bad, and many men were being discharged. So gloomy indeed was the outlook, that Mr. Anderson seriously contemplated going abroad to push his fortune in the Colonies; but before he could carry out this resolution, the circumstances arose which determined the course of his future life. Mr. D. Napier, in whose works he was employed in the spring of 1842, had, it appears, been employed from time to time by the Ordnance Department, and was then engaged in constr-

engine for the Royal Brass Foundry in the Arsenal. In connection with this, General Dundas, the then Inspector of Artillery, had called on Mr. Napier at his works, and the General mentioned incidentally that he was looking for a young engineer to take charge of the brass-gun manufacture, and of some new works in connection with it at the Arsenal. Mr. Anderson was at once suggested by Mr. Napier as being a suitable person; but the General hesitated when he noticed the apparently extreme youth of the pale-faced young man pointed out to him. It was, however, settled then and there that Mr. Anderson should be sent to the Brass Gun Foundry, to have charge of the erection of the engine, and the General would then have ample opportunity for observing how he managed matters, and be able to judge of his fitness for the vacant post. The erection of the engine, for some reason, entailed more than the ordinary trouble, and so conspicuous was Mr. Anderson's earnestness in the matter, that General Dundas determined to offer him the appointment of Engineer of the Royal Brass Foundry. The pay attached to the office was low, indeed less than he was earning at Mr. Napier's, but the field in the Arsenal was so open and inviting to an enthusiast in his profession, that he did not hesitate to accept the offer. This being, as it were, the point of departure in his life for the special work he was to perform for the country, it may be convenient to note the conditions of the situation. On the one hand, there was an energetic mechanic burning with desire to succeed, who from the appenticeship he had served, and from what he had seen in the best workshops of the country, possessed a thorough knowledge of mechanical construction in all its branches. Besides this, he was a good draughtsman and calculator, for although he had never learned to use the higher mathematics, he possessed a rare faculty in working out, by the simplest rules, questions of strains and similar problems of considerable complexity. He had also acquired, in the various ways above described, a sound knowledge of the laws of gases and liquids, and besides all this, his excellent memory was stored with general information. He was, however, devoid of experience in conducting work, for, as has been shown, he never remained beyond a few months in any of the large establishments where he might have had an opportunity of rising to a superior position. He also possessed a natural modesty which, at first at least, led him to feel diffident of his powers. The work before him was to effect a revolution in the gun-factories. The state of the gun-factories in 1842 was very unsatisfactory; since the close of the war in 1815, things had been in a quiescent state; the plant had become

obsolete, and the staff naturally somewhat indolent. The time had come when this was to end. The shops had to be enormously increased in size, and filled with machine-tools, and the workmen in them, growing in number to thousands, had to be trained to perform operations of the greatest delicacy. There was therefore an ample field for the full play of the energy of the young mechanic. Mr. Anderson set about his work with vigour. As he had a special aptitude for invention, new machine-tools, such as were specially adapted to the various processes in gun-manufacture, soon made their appearance in the shops, and the class of man who handled them was of a higher type than the old workmen. Mr. Anderson was from the first imbued with the conviction that properly designed machines could be made to relieve mankind of much manual labour, and later in life he often spoke of the development of labour-saving machinery, expressing his conviction that enormous strides would yet be made in that direction. The introduction of machine-tools was one of his steady aims throughout his service in the War Department, and it is believed that it was in the Arsenal that their advantages were first clearly seen and brought into play. Although it is impossible here to refer to the many and varied machines invented by Mr. Anderson at this time, one of them, the bullet-making machine, must be mentioned. It is unnecessary here to describe it in detail, but it profoundly impressed the War Office authorities with the mechanical genius which Mr. Anderson possessed. From his first entry to the Arsenal his daily labour was excessive. Actively superintending during the day, and inventing in his quiet home at night, was for eight years, with little rest, the record of his life. For not only had he the care of the gun-foundry, but the authorities, finding that they had in Mr. Anderson an engineer of rare talent, entrusted him with the preparation of new machinery for the manufacture of powder at Waltham Abbey. It is easy to understand that the elaborate action of the granulating-machine, incorporating-mills, dusting-machinery, &c., required for its perfecting much anxious thought, but one by one the difficulties were overcome, and the manufacture was brought to a high pitch of efficiency.

But though he had his hands full of hard practical work in-doors and out, he found time to give lectures to the Cadets in the Royal Military Academy on practical mechanics. These lectures, many officers have testified, were always interesting and instructive. The lecturer, as he went on, became more and more warm and enthusiastic over his subject, and it was difficult for the most indif-

ferent to be unaffected by the fervour of his address. The whole subject of applied mechanics was so familiar to him, that he rarely went through the fixed programme of the lecture, but would often be induced largely to amplify some part of the subject as he went along, and those unintended digressions were generally the most brilliant parts of his address. There was, besides the natural enthusiasm of the lecturer, another reason for the popularity of these lectures; the practical knowledge which he possessed of the things he spoke about, gave a force and solidity to his remarks which are always wanting in one speaking from a purely theoretical and literary knowledge.

The duties above described filled up the period from 1849 to 1853, and the time when the still greater effort was to be called for was at hand. His diffidence in himself had now gone, and he had become as bold and far-sighted in the application of machinery as he was learned in its details. He was also actuated by a spirit of patriotism as pure as ever filled the heart of a soldier. The war with Russia was imminent, and the Ordnance Board were beginning to realize how unprepared the Arsenal was to furnish war material in large quantities. The Board at once consulted Mr. Anderson, who, in what was called his leisure time, was asked to prepare a report on the introduction of steam-power into the Royal Laboratory. Immediately after this he had to report on the construction of a manufactory for making muskets by machinery. These reports, which led to the complete reconstruction of the laboratory plant of the Arsenal, and to the erection of the small-arms factory at Enfield, were written in snatches of time taken from the numerous duties which then rested on his shoulders. In 1854, he, with two Artillery officers, visited America and minutely examined the American system of small-arms manufacture; a large quantity of machinery was purchased, and an American engineer engaged to come over to England and take charge of the new factory at Enfield. He had hardly returned when, towards the end of 1854, a pressing demand came from the Crimea for Lancaster shells. Mr. Anderson at once promised the Board of Ordnance that he could erect a factory filled with machinery and plant, and have it in operation in two months. As the shells were formed of a single piece of wrought-iron, in shape like a champagne-bottle, this was a formidable task; but before two months were out, a shed of 30,000 square feet, containing four steam-engines, seven steam-hammers, and forty machines of various sorts—many of them original—were at work; and all this was done during a stormy winter season. Mr. Anderson himself has written, "the tear and

wear of mind and body to accomplish that task cannot be recorded." Another work which may be mentioned, out of the many in which he was engaged, was the preparation of a floating factory for the Crimea. This was fitted out in ten weeks, and dispatched with a picked body of artizans, and excited the admiration of foreign officers more perhaps than anything else done in the Crimea, as showing the determination of this country to be finally victorious. Many services cannot be here recorded; some may be named. Saw-mills had to be sent out to the Black Sea; supplies to the army of shot and shell had to be maintained; a new foundry and boring-mill had to be designed and erected in the Arsenal, and afterwards an extensive gas-works for the War Department in Woolwich.

In 1855, Mr. Anderson formed one of a Commission which visited the Continent, and reported on the manufacture of ordnance abroad, and finally he was a member of the Ordnance Select Committee, a body of officers specially charged with the investigation, for the guidance of the Secretary of State, of new suggestions or inventions in war material. Sir John during this period, 1853–57, made a surrender to duty of every minute not required for rest. He was therefore glad when there came a short period of comparative rest, as the superintendence of the War Department machinery, after 1857, for some time did not require exceptional exertion. This however did not last long, for in 1859 it was determined by the War Office, after many consultations at which Mr. Anderson assisted, to commence, in accordance with Sir W. Armstrong's views, the construction of rifled guns at the Arsenal. Mr. Anderson was selected to superintend the work while the system was being introduced, and the entire conduct of an establishment of about three thousand workmen was placed in his hands. Once more his energies were in full play, and so quickly were the new appliances brought into working order, that within twelve months one hundred and three 12-pounder guns were ready for service. When these extensive factories had been brought, in 1863, as near perfection both in efficiency and economy as Mr. Anderson could bring them, they were handed over to Royal Artillery officers to carry on, and he resumed his proper work of Superintendent of Machinery generally.

With the completion of the Armstrong Gun factories that period of intense exertion in the Arsenal, which had begun in 1842, came to a close, but Mr. Anderson was by no means idle. Apart from the ordinary duties of Superintendent of Machinery a variety of promiscuous occupations filled up his time. He wrote a book on

the Strength of Materials which has had a wide circulation. He delivered one of the series of Cantor Lectures for the Society of Arts, and for several years lectured on Applied Mechanics to the Royal School of Naval Architecture. He also acted as an Examiner to the Science and Art Department. He found time to devise improvements in the construction of railway plant, and held patents for these inventions. He was also consulted both as an arbitrator and adviser in the planning of engineering establishments, and in this latter capacity he rendered much assistance to the Turkish Government. But the employment which gave him most pleasure was that connected with the International Exhibitions, where his wide knowledge of machine construction made him a most reliable person to determine the merits of the various exhibits. In London, in 1862, and Paris, in 1867, he acted as a juror. At Vienna, in 1873, he occupied the more important post of Vice-President of the Jury for Machinery; while in Philadelphia, in 1876, and in Paris, in 1878, he was President of the Machinery Group, and materially assisted the executive in the general management of that department. This work was thoroughly congenial to him, and his success in it may be attested by the fact that he was appointed an Officer of the Legion of Honour by the French, and a Commander of the Order of Franz Josef, by the Austrian Emperor. After the Paris Exhibition of 1878 he was knighted by Her Majesty. He had been before this elected a Fellow of the Royal Society of Edinburgh, and the University of St. Andrew's had, in 1871, conferred on him the honorary degree of LL.D. Subsequently, in 1881, he was presented with the freedom of the City of Aberdeen, an honour which he highly prized, as it has been but rarely bestowed.

Sir John left the public service in 1872. The great expenditure of strength both of body and mind which had been put forth in the years 1842 to 1866, began gradually from the end of that period to be felt. Attacks of asthma and bronchitis from time to time began to trouble him and required that he should be most careful of his health. He therefore retired to St. Leonards with his books. It was difficult to believe that the once strong man, familiar with the hurry and bustle of life, could easily settle down to quiet retirement; but as his strength of body gradually failed he seemed to accept the situation with resignation and even content. When at home at St. Leonards, his days were spent in reading; works of a philosophic character, such as "Buckle's History of Civilization," were his greatest favourites. He had never any great liking for what may be called general society, but among

friends who would converse with him on some serious subject his manner was most charming and enthusiastic, and his remarks were always characterized by modesty, great breadth of view and liberality. He had married, in 1842, a wife by whose affectionate care he found in the busy part of his life always a peaceful home, and by whom during his last years he was nursed with tenderness and patience.[1]

WILLIAM FOTHERGILL BATHO was one of those born mechanics in whom the faculty of invention is inherent, and speaks with too loud a voice to allow of any doubt or hesitation in the choice of a career. He was the son of an engineer and tool-maker in Manchester, where he first saw the light, on the 11th of January, 1828. At the age of eleven he was apprenticed to his father for five years, and followed the usual routine of foundry, bench, and drawing-office. On the completion of his apprenticeship he was engaged for a year by the late Mr. C. E. Cawley, M.P., as an Assistant on the East Lancashire Railway, after which he returned to his father's works. Subsequently, in 1846, he entered the drawing-office of Messrs. Sharp Brothers and Co., under the late Mr. C. F. Beyer, M. Inst. C.E., where he remained for about a year. At the age of eighteen he emigrated to South Africa, with the intention of growing cotton in Natal. Considering his youth, it is scarcely matter for surprise that he failed in this undertaking, and, after trying several ways of gaining a living, he finally settled down as a Government Surveyor. In this capacity his duty was to survey, trigonometrically, the original grants given by Sir Harry Smith to the Dutch Boers, who at that time formed the principal population of Natal. In 1853 Mr. Batho returned to England, and found congenial employment in designing machines and tools, being for the next five years mainly employed with the firm of Messrs. Sharp Stewart and Co., for whom he designed, among other labour-saving appliances, the slot-drill. Being now desirous of enlarging his sphere of action, he went into business on his own account as an engineer and tool-maker, but his mechanical talent was greater than his business method, and after five years he relinquished his engagements to take the management of Messrs. Peyton and Peyton's tube-works at Birmingham. Four years later he became Manager of the world-renowned screw- and tube-

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[1] A very interesting autobiographical "Statement of Services Performed," from 1842 up to 1873, by the subject of this Memoir, is contained in Inst. C.E. Tracts, 8vo. vol. 240, in the Library of the Institution.

works of Messrs. Nettlefold, where likewise he remained four years. During this time he also practised as a consulting engineer, and in conjunction with his friend the late Mr. William Clark, M. Inst. C.E., he designed and patented the steam road-roller since made, under license, by Messrs. Aveling and Porter, of Rochester. He also had charge during their construction of the pumping-engines and machinery ordered by the Municipality of Calcutta for the drainage, and subsequently of other machinery for the water-supply of that city. Mr. Batho left Messrs. Nettlefold's to become managing partner of Sir Josiah Mason's steel-pen works, and to be engineering adviser in connection with the charitable institutions founded by that eminent philanthropist. For the last fifteen years of his life Mr. Batho practised as a consulting engineer in London, latterly in partnership with Mr. J. W. H. James, M. Inst. C.E., and achieved a considerable measure of success, his attention being largely devoted to the development of his numerous patents. In conjunction with Mr. Clark, he acted as engineering adviser and agent to the Municipality of Calcutta, and for the Calcutta Port Trust Commissioners, and continued in that capacity after the death of Mr. Clark. In association with Mr. William Duff Bruce, Vice-Chairman of the Calcutta Port Trust, he introduced the hydraulic dredger known by their joint names, which has met with an extended and very successful application, insomuch that the price of dredging in sand has been by its use carried as low as 1*d.* a cubic yard.[1] Mr. Batho was also Joint Consulting Engineer with Mr. Clark to the Oude and Rohilkund Railway, and designed the great bridge across the Ganges at Benares. More recently his name became widely known in connection with the open-hearth steel-melting furnace, which has been introduced as the Batho furnace, and is now in successful operation in many steel-works both at home and abroad.

Some few years ago his health began to fail, and after a lengthened illness he died at Bournemouth, on the 16th of May, 1886, at the age of fifty-eight. He was elected a Member of the Institution on the 6th of April, 1880.

In an exceedingly well-filled professional life, extending over more than forty years, Mr. Batho both saw and did much; but it was only during the latter period of his career that he had full scope for his energies. Doubtless had he lived he would have risen to the highest rank in the profession; as it was he attained to within measurable distance of it. It is impossible in a short

[1] Engineering, Dec. 5, 1884.

notice like this to convey an adequate idea of his eager intelligence and mental activity, but both are attested in the record of his patents. Of these the most notable, and those by which he will be remembered, are the double-traversing grooving- and drilling-machine;[1] the nut-shaping machine;[2] the steam road-roller;[3] the open-hearth steel-melting furnace, and the hydraulic dredger-excavator[4]; all of which were eminently successful practical inventions.

ALEXANDER WOODLANDS MAKINSON was born at Higher Broughton, Manchester, on the 30th of July, 1822, and was a spectator of the opening of the Liverpool and Manchester Railway. Leaving the Manchester Grammar School at an early age, he was apprenticed for five years to the Surveyor to the extensive Clowes estates, and at the expiration of that time became the pupil of Mr. G. W. Buck, M. Inst. C.E., by whom he was set to work on the Watford section of the London and Birmingham Railway. At the expiration of his pupilage in 1842, he went through a three years' course in the engineering department at King's College, London, from whence he proceeded to Lowestoft to take charge of the construction of the pier for the Eastern Counties Railway, of which the late Mr. James Samuel, M. Inst. C.E., was Chief Engineer, and by whom he was engaged to superintend the survey and construction of the Newmarket and Ely and Hartingdon Railways, and in preparing the plans for a proposed water-supply for London from the Bala lake. About this time Mr. Makinson was employed under Sir James Brunlees, Past-President Inst. C.E., on the Lancashire and Yorkshire Railway. In 1851, having assisted the late Sir Goldsworthy Gurney in the ventilation of the Houses of Parliament, he entered into partnership with the late Mr. W. Clark, M. Inst. C.E., as sanitary and ventilating engineers, the partnership expiring on Mr. Clark receiving the appointment of Engineer to the Municipal Council of Calcutta. Mr. Makinson was then occupied for some years in superintending the construction of, and afterwards as Resident Engineer on, the Llanelly and Vale of Towy Railways; he also went to Switzerland in 1854 for a few months under the late Mr. Hemans, Vice-President Inst. C.E. In 1859 he received the appointment of Chief Engineer on the Calcutta and South-Eastern

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[1] Institution of Mechanical Engineers. Proceedings. 1856. p. 111.
[2] *Ibid.* 1869. p. 312. [3] *Ibid.* 1870. p. 109.
[4] Engineering, Oct. 3, 1879.

Railway, but was obliged to resign after about a year's service owing to fever and ague, being also obliged for the same reason to decline the appointment of Chief Engineer to the Bombay and Baroda Railway. Soon after his return from India, Mr. Makinson proceeded with Mr. Samuel and several other engineers to the Isthmus of Panama, to check the surveys of the French engineers for the Atlantic and Pacific Ship Canal, projected by the late Emperor Napoleon III.; and at Greytown, perhaps the most unhealthy spot in the world, he contracted malarial fever, which incapacitated him for a long time from actively following the duties of his profession. He was consequently only able to work at intervals during the period from 1860 to 1867 in making surveys for several proposed new lines, such as the Birkenhead Docks and Cheshire Railway, the widening of the Altrincham and Sheffield Junction Railway, the Liverpool Extension Railway, the Manchester Central Station, and the Hooton Branch of the Manchester, Sheffield, and Lincolnshire Railway. During 1866–70 Mr. Makinson acted as Resident Engineer on the Carnarvon and Llanberis Railway, which was subsequently incorporated with the London and North-Western Railway system. In 1871 he was engaged in laying out and superintending the construction of the Halmstad-Nässjö Railway, in Sweden, 120 miles long, with which he was concerned till 1877, when, owing to the failure of the Swedish Bank, which had purchased the bonds of the line, the work came to a standstill, 80 miles having then been completed and opened for traffic. During the latter years of his life Mr. Makinson withdrew from professional work and employed himself in farming in Sweden, where he expired at Herrestad Kärda, after a short illness, on the 14th of April, 1886. Gifted with brilliant mathematical powers, combined with a thorough knowledge of his profession, remarkable for integrity of life and aim, he lived and died a Christian gentleman of the highest type, leaving a memory which, to quote the words of a friend, in itself constitutes a rich inheritance for his children.

Mr. Makinson was elected a Member of the Institution on the 1st of February, 1859, and received a Telford Premium for a Paper "On some of the Internal Disturbing Forces of Locomotive Engines," read on the 2nd of December, 1862.

JAMES MATHIAS, the seventh son of the late Charles Mathias of Lamphey Court, Pembrokeshire, was born on the 23rd of November, 1823. He was educated at Bruton School, in Somersetshire, under

the Rev. John Hoskins Abrahall, from whence he entered the College of Civil Engineers, at Putney, in 1841. He left that institution in 1844, and, having become a pupil of Mr. (now Sir John) Hawkshaw, he commenced work under Mr. Gouch, the Engineer of the Manchester and Leeds Railway, and, in 1845, became actively engaged as Resident Engineer on the Miles Platting and Ashton-under-Line branch; he was also given charge of the Oldham Extension. In 1846, when Mr. Gouch retired from the service of the Company, which became the Lancashire and Yorkshire, Mr. Mathias was engaged on the parliamentary work of the Sheffield, Rotherham, Barnsley, Huddersfield, Wakefield and Gould railways for two or three years, and was then appointed Resident Engineer of the Halifax division of the West Riding Union Railway. About the year 1852 he became Chief Engineer to the Wigan and Southport branch of the Lancashire and Yorkshire Railway, and completed the works of this branch in the years 1853 and 1854. He afterwards determined to visit the East, and travelled in Egypt during the years 1857 and 1858. In 1859 he was again in England, engaged in surveying railways in South Wales; and from 1862 to 1865 he was the Engineer of the Pembroke and Tenby Railway and Extensions. Subsequently he set out a railway in Prussia, and works in Holland in the winter of 1869. Here he was attacked with illness from exposure to cold from which he never recovered, and from that time he was practically out of business; occupied with the management of some landed property which he had inherited, and to which he made considerable additions, the details of building and the general management of his private affairs for some years before his death constituting his sole employment. He was a man of very retiring disposition, but always kind and generous to those who served under him, taking an interest in all his staff and dependents. He was elected a Member of the Institution on the 7th of April 1868, and he died on the 5th of June 1886.

EDWARD NEWCOMBE was the second son of Mr. W. L. Newcombe, Traffic Manager of the Midland Railway, and was born at York on the 1st of September, 1843. He was educated at Shrewsbury Grammar School; and at the age of sixteen he entered the locomotive department of the Midland Railway, under the late Mr. Matthew Kirtley. Five years later he became a pupil of the late Mr. John Crossley, M. Inst. C.E., Chief Engineer of the Mid-

land Railway Company, and was afterwards appointed an assistant engineer on the construction of the Chesterfield and Sheffield Railway. In 1870 Mr. Newcombe became an assistant resident engineer on the Settle and Carlisle line, and in the following year Resident Engineer. In 1873 he left England for Japan, on his appointment by the Japanese Imperial Government, under Mr. R. Vicars Boyle, C.S.I., M. Inst. C.E. Here he was engaged in locating and setting out a line of railway through a close and difficult country, being chiefly occupied on the Kioto, Surunga and Nagasendo and Owari lines. On the completion of this work Mr. Newcombe started for England; but on arriving at Hong Kong he was induced by the Surveyor-General to superintend the construction of harbour works then in progress. However, a change of Colonial Government in 1877 put a temporary stop to the work, and Mr. Newcombe returned home at the end of that year, and re-entered the service of the Midland Railway Company as Resident Engineer on the South Wales lines.

Mr. Newcombe was distinguished for his extreme gentleness of character and winning manner, and gained the esteem and regard of all who came in contact with him. He was universally beloved by his men, to whom it was said he never used a harsh word. His early death and long sufferings may be attributed to his devotion to his duties. He first contracted a severe form of rheumatic arthritis by long exposure to the weather during the heavy snow-storms of the winter of 1881. This gradually increased in severity until he became completely crippled, notwithstanding which he fought against the disease, whilst still performing his duties to the utmost. Mr. Newcombe died at Bournemouth on the 17th of January, 1886. He was elected a Member of the Institution in February, 1878.

JOSHUA RICHARDSON, one of the oldest Members of the Institution of Civil Engineers, was born at Bishop Wearmouth, in the county of Durham, on the 10th of February, 1799. He was descended from a family long noted in the north of England for upright conduct, sound judgment, and great decision of character. His father, John Richardson, in 1814, was one of the first men who introduced steam-power for the grinding of bark in his tan-yard, and utilizing it as the motive-power in his flour-mills. The novelty of this adaptation created great interest in the district, and numerous visitors from a distance came to witness the successful application of this powerful accessory to science.

Joshua Richardson received a sound education; his mental development was not rapid, but he was very persevering, and being of a reflective temperament, studious habits, and a hard reader, associating also with intelligent companions, he obtained much information in scientific knowledge, natural philosophy, and general literature, also in geology. He always traced his predilection to engineering to the delight he had as a boy watching day by day the progress of the erection of the high-level bridge at Sunderland, over the river Wear, at that time regarded as a marvel of engineering skill. He was trained in youth for mercantile pursuits, and it was not till early manhood that he resolved to pursue the profession of a civil engineer.

He became an articled pupil of George and Robert Stephenson, about the time of the opening of the Stockton and Darlington Railway, when the railway system was about being generally adopted in the country. He had the privilege of close intercourse with Robert Stephenson, to whom he was much attached, also of being introduced to some of the leading engineers at that time. He prized the opportunity afforded of becoming acquainted with practical engineering in the factory and drawing-offices of Robert Stephenson and Co., at Newcastle, and used to advert to the instruction gained there as being of service to him in his after-career. He assisted in surveying several of the early railways, and had to give evidence on the levels of the Newcastle and Carlisle Railway before a Parliamentary Committee. His first appointment, as Resident Engineer, was under Robert Stephenson, on the Canterbury and Whitstable Railway and harbour. The gradients of the railway were such as to require a tunnel, and a steep incline was worked by means of a stationary engine and rope. This railway was the first in the south of England opened for general traffic. He took an active part in the arrangements, and its completion was the cause of great rejoicing in Canterbury and the vicinity.

On the opening of the Liverpool and Manchester Railway, as belonging to the engineering staff, he was placed on one of the locomotives in the processsion. In after-life he would dilate on the triumphant success of the enterprise—though sadly clouded by the melancholy death of Mr. Huskisson, of which mournful event he was an eye-witness. He surveyed a line of railway from Newcastle to Shields, and was employed on some of the Midland railways. After completing his term of pupilage, he was appointed Engineer and Manager of the works of the Canterbury and Whitstable Railway. In 1832 he settled in the North. He was elected

a Member of the Institution of Civil Engineers on the 28th of January, 1834, and took great interest, when opportunity offered, in attending the meetings. He was appointed Engineer of the new Water Company in Newcastle, and prepared the Parliamentary plans and estimates for the waterworks, and superintended their construction. The Commissioners of the River Tyne and the Newcastle Corporation engaged him to survey and report on the deepening of the river. In 1836 he published his report "On the best practical means of improving the navigation of the River Tyne, with an appendix on the River Clyde at Glasgow." Previous to this, the second edition of his "Observations on the proposed Railway from Newcastle-on-Tyne to North Shields" was issued. For several years his time was devoted to the promotion and preliminary surveys and plans of railways in the North of England and Scotland, also in colliery practice.

Desirous for the improvement of the colliers and others resident in the North Durham district, with the aid of the late Mr. Hutt, M.P., and some local gentlemen, he took an active part in establishing the Literary and Mechanical Institution in Burnopfield, of which he became Vice-President. The Newcastle Corporation awarded him a premium for the original plan of the steam-boat jetty erected on the River Tyne, the principle of which was afterwards adopted in several other seaports. On the completion of the London and Croydon Railway in 1839, he was elected Engineer of the Company and Manager of the working details of the line. Subsequently he removed into Wales, on his appointment as Engineer and Managing Director of extensive collieries and railways in Glamorganshire. He was also engaged to select, and to survey, the line of the Vale of Neath and Merthyr Railway, and he prepared the necessary plans and estimates; the works were afterwards executed under the patronage of the Great Western Railway, to whom the line is now leased. He obtained the premium offered for the best plan of the Burnham Docks and Harbour in Somersetshire. He had considerable practice in reporting on the coal-fields, and the best mode of working the coal of North and South Wales, the Forest of Dean, and the West of England, and was engaged on slate quarries, lead, iron, and copper mines. He had professional employment in Belgium and in France, where he furnished a report "On the extensive deposit of magnetic iron ore at Diélette, near Cherbourg, and the best mode of working and converting it, with estimates, plans, and sections." This report was published in 1866. For a long series of years he was the Consulting Engineer of the late Lord Craven for his coal-fields in

the Clee Hills, Shropshire, and at Coventry in Warwickshire. He acted in the same capacity for Sir William R. Clayton, Sir Charles Boughton, the Neath Abbey Coal Company, and many others. In the valuation of coal property and colliery plant he was often applied to as a trustworthy authority. In law, in arbitration, and in Chancery suits connected with engineering, he had much experience, and was frequently required to examine, report on, and give evidence in the public Courts.

Of his publications, the work "On the Prevention of Accidents in Mines" was a subject he had naturally considered, and felt convinced that if the sanitary measures practised in the best regulated collieries were legally enforced, they would tend to diminish suffering and loss of life. The book was very favourably reviewed by the press. It had a wide circulation, and obtained the attention of several members of the Government. Lord Wharncliffe wrote to him respecting its object, and arranged for his giving evidence before a Committee of the House of Lords appointed to inquire into the subject of inspection of mines. After the Bill enforcing inspection was passed, Joshua Richardson had frequent intercourse on professional subjects with the newly-appointed inspectors, especially with his old experienced acquaintance, Mr. Matthias Dunn, of the Northern district, and with Mr. Herbert Mackworth, of South Wales, who always enjoyed conferring and consulting with him on topics affecting the safety of mining operations. He was extremely neat and methodical in the arrangement of his books, papers, plans, and correspondence; noted for writing clear, explicit, and comprehensive reports, and often surprised those who consulted him by the correctness of his geological and engineering knowledge.

He was the Author of four Papers communicated to the Institution; namely, 1. "On the Ventilation of Mines," read on the 23rd of March, 1847;[1] 2. "The Coal-field and the Coal of South Wales," read on the 13th of February, 1849.[2] At a time when the rapid exhaustion of the coal in Great Britain was occupying the public mind and creating alarm, this Paper attracted much attention, and was, by permission of the Council, re-published in the Bristol and Glamorgan Directory. 3. "On the Explosion of Fire-damp which occurred in the Eaglebush, or Eskyn Colliery, near Neath, South Wales, on the 29th of March, 1848," read on the 20th of February, 1849.[3] 4. "On the Pneumatics of Mines," read on the

[1] Minutes of Proceedings Inst. C.E. vol. vi. p. 160.
[2] *Ibid.* vol. viii. p. 82. [3] *Ibid.* vol. viii. p. 118.

1st of February, 1853.[1] For the first of these papers he received a Telford medal, and for the others premiums of books. He much valued the Minutes of Proceedings of the Institution, which were to him treasures of science, and each volume was duly read and the plans examined. He had the whole series from the beginning, neatly bound and arranged, and until late in life he would comment with enthusiasm on the amount of practical engineering they embodied. Desirous of spreading the advantages of the Institution, he frequently recommended young rising engineers to become candidates for admission, taking care that none but those who fulfilled the stipulated conditions should aspire to the honour. He was warmly interested in young men entering on active life, especially in those employed by him, watching over and advising them for good. He showed much tact in managing and organizing bodies of working men, maintaining his authority and yet gaining their respect and regard. For many years he was a contributor to the columns of the "Mining Journal," discussing the various topics engrossing the attention of engineers.

In 1846 he was elected a Fellow of the Geological Society. He was a good walker, and occasionally accomplished 40 miles a day; the exploring of rocks, examining the strata, collecting fossils and other specimens, were all sources of pure pleasure, as well as being serviceable in mining and engineering operations. He would often encourage his younger friends to pursue this branch of knowledge, so as to enhance the interest of their excursions and pedestrian tours.

Not only as a man of science was Joshua Richardson active and energetic, but he was equally so in the cause of philanthropy. Kindness and tenderness of heart were his distinguishing characteristics, and he could not witness misery and suffering without desiring so relieve it; as far as circumstances warranted, he was prompt to succour the distressed. He had not wealth to bestow, but he had the pen of a ready writer; was a good and fluent speaker, and could eloquently plead the claims of justice and humanity. Often solicited to take part on the platform in public matters, he was bold to speak according to his convictions, but was no blind partizan. Trained as a member of the Society of Friends, and sound in the faith of that Christian body, he maintained and advocated the doctrine of peace and good-will to all mankind, and he was local Secretary of the Peace Society. He took part as well in the Anti-Slavery cause. He was deeply imbued with the love

[1] Minutes of Proceedings Inst. C.E. vol. xii. p. 272.

of the Bible, and the sublime truths of the gospel, and for ten years he was Secretary of the Neath Auxiliary Bible Society. He united with others in forming a Benevolent Society in Neath for the relief of the deserving poor, and acted as secretary. He was eminently the friend of education, believing it to be the basis on which mainly depended the progress and elevation of the lower classes. The ignorance prevailing in some parts of Wales, especially amongst the colliers, deeply impressed him with the need of elementary schools. Encouraged and assisted by some of the best and most benevolent men in the district, and by their generous co-operation, he was instrumental in establishing the "Neath School Society," of which the British School, with similar schools, were the results. He with others took a warm interest in the erection of commodious schools for boys, girls, and infants. For upwards of twenty years he acted as Government correspondent, manager, and honorary secretary, and was said to be "the mainspring of the movement." He was also Honorary Secretary to the school in connection with the Neath Abbey Ironworks. In 1872, at a numerous meeting at the Town Hall, Neath, he was presented by the friends of education, as a testimonial of their approval, with a silver tea- and coffee-service of elegant design, on which the following inscription was engraved: "Presented to Joshua Richardson, M. Inst. C.E., F.G.S., in recognition of his services in the cause of unsectarian education in Neath, 1872."

Though of a retiring, unobtrusive disposition, he was cordial, courteous, and refined, with a well-stored mind full of resources, and he possessed good conversational powers. He was thoroughly domestic in his habits; home was his delight, and his chief earthly happiness was in the bosom of his family. The one great sorrow of his life was the loss of his only son, of whom he could rarely speak in after-life without deep emotion. He died on the 22nd of March, 1886, at the age of eighty-seven.

DAVID THOMSON was born on the 15th of November, 1816, at Maxton Manse in Roxburghshire, his father, the Rev. John Thomson, being the parish minister of that place. After receiving a good ordinary school education, as his abilities and inclinations appeared to tend towards a mechanical career, he passed through a suitable scientific curriculum at Glasgow University, and was afterwards apprenticed to the mechanical engineering firm of Messrs. Claud Girdwood and Co., of Glasgow, removing, on the

closing of that establishment, to the well-known factory of Messrs. Nasmyth, Gaskell and Co., of Patricroft, Manchester.

He was afterwards employed temporarily by the Peninsular and Oriental Steam Navigation Company, and one or two other firms, when he made the acquaintance of the late Mr. Archibald Slate, M. Inst. C.E., who, discovering in him an extraordinary mechanical ability, induced him to come to London, and obtained for him in 1845 the important post of Manager of the large engineering works of Messrs. William Simpson and Co., then in the Belgrave Road, Pimlico. Here he remained for twenty years, during which time he had responsible charge of the design and construction of a very large quantity of engines, machinery, and iron structures of various kinds, which for correctness of principle and excellence of workmanship, obtained for the firm the highest character in the engineering profession. In July 1865, he took a similar position with the old-established firm of Messrs. Richard Moreland and Son, mechanical engineers, in the Goswell Road, where he remained till 1877. For the first two years of this period he was also engineer in charge of the pumping arrangements, and the driving of an adit about 3 miles long, at Lichfield, for the South Staffordshire Waterworks. In 1877, finding his health giving way, he relinquished his active position at the manufactory, but still continued to give the firm the benefit of his occasional advice and assistance so far as he was able, until September 1881. He died at his residence, Craighead, Belvedere, Kent, on the 11th of April, 1886.

Mr. Thomson was a man of great intellectual capacity. He was well grounded in mathematical and physical science, and applied this knowledge with good judgment and common sense to practical engineering. This was shown by the satisfactory and successful results of the works designed and manufactured under his direction during his long term of practice, some of the most important of which may be mentioned here.

About 1848 the first great step was made in the modern improvement of the London Water-Supply, by the removal of the intake to a position above the tide-way of the River Thames. The pioneers in this were the Lambeth Water Company, under the guidance of their Engineer, Mr. James Simpson, Past-President Inst. C.E. The water was taken from the river at a point near Thames Ditton, and had to be conveyed along a large main 10 miles long, from thence to the company's reservoirs at Brixton and Streatham. This involved important considerations in regard to the pumping arrangements, and Mr. Simpson confided to Mr. David Thomson, in conjunction with Mr. William Pole (now

Honorary Secretary of the Institution of Civil Engineers), the task of investigating the matter. After many enquiries and experiments, they recommended the use, for the purpose, of compound-cylinder engines. This form of engine, although an old invention, was at that time imperfectly understood, and the specimens of it in existence showed little trace of the advantages that have since been derived from it. Mr. Thomson and his coadjutor pointed out, however, that the principle was capable of highly beneficial use, and that it was, moreover, for many reasons, peculiarly applicable to the case in question. Their recommendation was adopted by Mr. Simpson, and Mr. Thomson undertook to design and manufacture engines for the purpose. There were two pairs of engines, giving a total of 600 HP.; they were set to work in 1852, and were successful in all points of view.[1] They were afterwards copied for many other large waterworks, where circumstances were favourable for their use. In the course of this work Mr. Thomson introduced a new form of double-acting pump, called the "Bucket and Plunger Pump." The principle of it had been indicated in a rough form by Smeaton in 1759,[2] and Mr. Thomson, finding it offered special advantages for waterworks purposes, took it up and perfected its design in modern form. It has since been much used. He made large numbers of steam-engines for waterworks and other purposes, some of considerable magnitude, and he evinced great skill in adapting them, so as to produce the maximum efficiency for the work they had to do. For some special cases he designed an improved form of tubular boiler, for which he took out a patent in 1868.

He was one of the best authorities on waterworks machinery, great quantities of which of all kinds were made under his direction, and all of a high degree of efficiency. He took great interest in the development, for useful practical purposes, of the centrifugal pump, in which he made and patented valuable improvements. Between 1867 and 1874 he constructed large hydraulic appliances of various kinds for the Metropolitan Main Drainage Works, and he introduced therein a new form of pump-valve of large dimensions, which has since been extensively used.

Among the miscellaneous works designed by him may be mentioned an improved road roller of large size, built for H.M. Office of Works and elsewhere; power-capstans for Chatham

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[1] Institution of Mechanical Engineers. Proceedings. 1862, pp. 242, 259.

[2] "An Experimental Enquiry concerning the Natural Powers of Water and Wind to turn Mills, &c." Phil. Trans. vol. li. p. 100.

Dockyard; coal-tips for Leith Docks; dredging engines; tanks for large submarine cables; and new entrance-gates for the Bute Docks, Cardiff.

In 1876 he was made a Director of the Crystal Palace; he gave great attention to the many and important engineering works of the establishment, and during certain periods of anxious doubt as to the policy and management of that great undertaking, he exerted himself actively in the investigations that were made, and his judgment carried great weight with his colleagues.

Mr. Thomson always maintained a high personal character, which commanded the respect of all who knew him. He was fully master of his business subjects, not only in their scientific and constructive aspects, but also in their commercial bearings; and his aid was often sought in arbitrations and disputes where high integrity and sound judgment were required. He never aspired to an ostentatious position, but he was one of those whose works have gained for Great Britain the character of the first mechanical nation in the world.

He was elected an Associate of this Institution in March 1845, and was transferred to the class of Member in January 1878. He presented an Original Communication to the Institution on "Centrifugal Pumps,"[1] which was read on the 14th of February, 1871. He was a frequent attendant at the meetings, and often gave his professional brethren, in the discussions, the benefit of his ample store of knowledge. He married, in 1846, the daughter of the Rev. Archibald Bruce, of Stirling, and several of his sons hold appointments under Government.

JOSEPH SALTER OLVER was born at Falmouth on the 18th of November, 1818. He served a pupilage of three years (1834–37) as a surveyor and civil engineer to a Mr. Rutger of Penzance, with whom he subsequently remained for some time as an assistant in several undertakings in Cornwall and Devonshire. Afterwards, until 1840, he was employed by a firm of builders and contractors to the members of which he was related; he also attained some local repute as a surveyor at this time. In 1840, when the extension of the railway system into Cornwall was first mooted, Mr. Olver was engaged by Capt. W. S. Moorsom and Mr. Brunel to assist in the preliminary surveys, and, with the

[1] Minutes of Proceedings Inst. C.E. vol. xxxii. p. 26.

exception of an interval when he was employed by Mr. Rendel on the Falmouth Harbour works, he remained on the Cornwall Railway until the system was practically completed in 1855. Towards the close of the Crimean war, in 1855–1856, Mr. Olver obtained an appointment as Assistant Superintendent of Works under the late Mr. W. T. Doyne, M. Inst. C.E., who was engaged under the War Office, and after the Proclamation of Peace, remained for some time in the same department. Subsequently, until 1863, he was employed by Messrs. Walker and Burges, and by Mr. Fowler, Past President Inst. C.E., also in the engineering department of the Metropolitan Board of Works. In the year named he became assistant to Sir John (then Mr.) Coode, Vice-President Inst. C.E., and was engaged in preparing designs for coastworks, railways, drainage, and on various surveys, &c. Eventually he was employed by the Metropolitan Board of Works under Sir Joseph Bazalgette till December, 1885.

Although making no claim to be other than one of the rank and file of the profession, Mr. Olver was a competent engineer, and in the course of nearly half a century of active life he gained the esteem and confidence of all those with whom he became associated. He was elected an Associate Member of the Institution on the 2nd of February, 1875, and died on the 17th of March, 1886.

PATRICK ADIE was the youngest son of the late Alexander James Adie, F.R.S.E., optician of Edinburgh, and brother of the late Engineer of the Edinburgh and Glasgow and other railways. He was born in 1821, and was educated at the High School of Edinburgh. On leaving he went to the workshops of Messrs. Milne and Son, gas engineers, in that city, where he gained his first mechanical experience. The next four years were spent in his father's workshop in Edinburgh, with the exception of six months, which he passed in Sir Thomas Macdougall Brisbane's observatory, near Kelso, where he gained valuable information, and made the acquaintance of the late Mr. John Welsh, subsequently Superintendent of the Kew Observatory. About 1847 he came to London, and a few years afterwards set up in business as an optician and surveying-instrument maker, which business he continued till the time of his death. He designed and supplied many of the instruments used by the engineers engaged in the great trigonometrical survey of India, and also in the construction of many railways, both in this country and abroad. He gained

medals at the Exhibitions of 1851 (London), 1855 (Paris), 1862 (London), &c., for excellence of these instruments. For meteorological instruments his reputation was fully sustained, many certificates being received from Kew Observatory, showing that they were without error. That Mr. Adie possessed great inventive power is shown by the fact that he took out no less than twelve patents, many of which are well known, and have proved very successful. One of these patents he was engaged in perfecting at the time of his death. It consists in the employment of corrugated steel belting, in lieu of leather, which he believed would effect a large saving both in power and cost. In this opinion he was supported by some eminent Members of the Institution, to whom he was well known, and who frequently sought the advice which his great experience enabled him to give.

During the last ten years of his life he had suffered from bronchitis and heart disease. He died suddenly on the 18th of May, 1886. He was elected an Associate of the Institution on the 2nd of May, 1865.

Lieutenant-Colonel PATRICK MONTGOMERIE, R.E., was born on the 26th of October, 1837. He obtained his first commission as Second Lieutenant in the Madras Engineers on the 13th June, 1856, and after the usual course of practical instruction at the School of Military Engineering, Chatham, he proceeded to India, and reached Madras in June, 1858. Arriving in India after the Mutiny, and being posted to the most peaceful of the Presidencies, it was not his fortune to see any active service in the field. In the ordinary course of promotion he rose in military rank as follows: viz., First Lieutenant, 27th August, 1858; Captain, 7th March, 1868; Major, 3rd February, 1875; Brevet Lieutenant-Colonel, 3rd February, 1882; Regimental Lieutenant-Colonel, 4th June, 1883.

His first occupation in civil duties appears to have been in conducting some boat experiments under the immediate order of the then Chief Engineer, Colonel (afterwards Sir Arthur) Cotton. In November 1860 he was transferred as Assistant Engineer to the Godavery District; a chief centre of irrigation work in connection with the great dam and system of canals, which had been projected and carried out under Sir Arthur and his brother Frederick Cotton; and there he laid the foundation of that practical knowledge of irrigation engineering which made his

services so valuable in that special branch, to which he remained devoted throughout his career. He left the Madras Presidency for the Central Provinces in June 1864, obtaining promotion as an Executive Engineer, 4th Grade, in November, but was driven home by ill health in October 1865. Returning to duty in December 1868, he was employed for upwards of four years in the irrigation districts of Tanjore and Trichinopoly, where he had charge of the works in connection with the River Cauvery, originated by native engineers under a former government, but put into their present state of efficiency by Sir Arthur Cotton and the school of engineers who are still proud to look up to him as their chief. It showed appreciation of his abilities and good work that Captain Montgomerie was called up to Madras in March 1873 to fill the post of Deputy Chief Engineer and Under-Secretary to Government in the Department of Public Works, which he held till he went home on two-years' furlough in March 1874; and neither on this nor on the subsequent occasion when he filled a similar office in the irrigation branch, from September 1877 to March 1879, did he fail to recommend himself by his efficiency and genial character, not only to his immediate chiefs, but also to the members of government, and to the body of officers whose interests he to some extent represented. He gained the respect and esteem of all with whom he had to transact departmental business. In fact, he was an officer of varied resources, and officiated as District Engineer of Madras itself, and as Consulting Architect to Government, from the date of his return from furlough in March 1876 till nearly the end of that year, spending the next twelvemonth in the Salem district. His subsequent appointments were as follows, viz.: Acting Superintending Engineer, 4th Circle, March 1879; on special duty, Tanjore Delta, July 1880; furlough two years—March 1881 to February 1883; on special duty in connection with the Tanks Maintenance Scheme, February 1883; concluding finally with the charge of the First Superintending Engineer's Circle from May 1884; in which was included the Godavery Irrigation Works on which he gained his first experience.

It was while on one of his tours of duty as a Superintending Engineer that he was carried off by a sudden attack of illness at Waltair, near Vizagapatam, on the 8th of January 1886, to the deep regret of all who knew him.

"The most notable work that he did," writes one most competent to judge, "was the investigation in 1880 of the cause of the great floods in the Coleroon and Cauvery Rivers. This special

work was most ably carried out: and the report is a most valuable contribution to the literature of river floods, their causes, and their proper treatment. On the information collected by him the design for the Cauvery and Vennar Regulators at the Grand Annicut near Trichinopoly, was modified, and the estimates were sanctioned by the Government of India. These great works must now be nearly if not quite completed."

The Tanks Maintenance Scheme was one also on which Colonel Montgomerie bestowed much thoughtful attention. It was a subject of great financial importance, inasmuch as the revenue dependent on these (comparatively) minor irrigation works of the Madras Presidency, is 36 per cent. more than that derived from the whole of the great delta systems, and amounts to three-fifths of the entire irrigation revenue. But it was a matter requiring to be handled by an expert in Irrigation Engineering; and the Government Order disposing of his report acknowledged that it was the first time that this important question had been systematically and scientifically treated. Colonel Montgomerie's able report showed what could and what should be done to bring up every irrigation work in the presidency to a proper standard of efficiency, and to maintain them in it: and his recommendations are to be carried out, though such action was not thought to necessitate any such radical changes in the constitution of the Public Works Department as his further proposals involved.

The deceased officer was married in 1875 to a daughter of General Macleverty, formerly Commander-in-Chief of the Madras Army, whom he left a widow with two young children. Colonel Montgomerie was elected an Associate of the Institution on the 5th of May 1868.

MAJOR AND BREVET LIEUT.-COLONEL JAMES LAW LUSHINGTON MORANT, R.E., obtained his commission as Lieutenant on the 10th of June, 1859, was promoted Captain on the 14th of January, 1871, and Major on the 22nd of August, 1877, receiving his brevet rank as usual seven years later. The son of a Madras Army Chaplain, he naturally selected that Presidency as his sphere of work. Here he was posted to do duty with the Sappers and Miners in January, 1862. But his first employment on Civil duties was in Bombay, where great activity prevailed in the Public Works Department, under the energetic rule of Sir Bartle Frere, who insisted on the appropriation for local purposes of a portion of the

large sums realized by the sale of the valuable building sites previously occupied by the obsolete fortifications of that city; and Lieutenant Morant's services were requisitioned from Madras to help in the prosecution of the New Harbour Defences, at which he worked first as a special assistant, and afterwards as Executive Engineer, 4th Grade, from January 1864 to December 1865. He was then appointed to the Mitron Canals, in Sind, with a step in departmental rank, but does not appear to have joined, and was employed at Kaira, in Guzerat, till October 1866. From this date till his return to his own Presidency, in June 1869, he was in sole charge of the new road from Belgaum to the coast, *viâ* the Ambolee or Parpoolee Ghaut.

The experience gained in building operations at Bombay and in the engineering of mountain passes stood him in good stead in his new location on the Neilgherry Hills, which he only left to take a well-earned furlough in September 1880. The Lawrence Asylum works at Ootacamund were there completed under his supervision; the Military Barracks at Wellington were under his charge; the New Coonoor Ghaut required to be metalled and constantly attended to; to say nothing of the Ghaut Roads to Kotahgherry, the Wynaad, and Mysore, all laid out on elaborate traces and exposed to the action of heavy monsoons; and the numerous civil buildings at Ootacamund, the seat of Government for six months in the year. It was a sphere of work for which he was peculiarly fitted by those qualities which constituted him an Honorary Associate of the Institute of British Architects, as well as an Associate of the Institution of Civil Engineers. At the same time it was an onerous charge, which he successfully sustained for a period of eleven years, rising to the 1st Grade of Executive Engineers.

On his return from furlough in October, 1883, he was appointed Civil Architect to the Government for eighteen months, in the place of Mr. Chisholm; and then for twelve months after that gentleman's return to duty he became Superintendent of Works on the Buckingham Canal, with a short interval spent in acting as Superintending Engineer of the Kistnah Division. The work of the canal suited neither his habits nor his health, and he was forced to give it up in April 1886, and proceed to Australia in hopes that the sea voyage and change of climate would conduce to his recovery from the liver complaint, which it had developed. His medical attendant and friends were far from anxious about him, and his return in health was so confidently expected that in his absence he was appointed to succeed Mr. Chisholm permanently

as Civil Architect to Government, as the fitting reward for the ability with which he had filled that gentleman's place, with the carrying out of whose elaborate designs for the new post and telegraph offices at Madras he had much to do. But in spite of every care and attention paid him by relatives at Melbourne the disease grew upon him, and had a fatal termination on the 17th of June.

Colonel Morant took much interest in all branches of his profession, and was a valued contributor to the Indian Engineering Papers, published at Roorkee (the Professional Papers of the Madras Engineers having long since ceased to appear). Although he was never employed on railway works he was well read on the subject; and when the question of extending the Madras Railway from the foot of the Coonoor Ghaut to its crest at Coonoor, a rise of 5,000 feet, came seriously to be entertained, he spared no pains, while Executive Engineer on the Neilgherry Hills, to have the project worked out to a practical issue. His Report to the Madras Government on the subject, printed with their Order, No. 1,213, of the 30th of April, 1875, was a voluminous and exhaustive document, entering into detailed comparisons of the suitability of the various existing systems of railways working on steep inclines to the special locality in view, and of their cost of construction and maintenance; and concluding that the Rigi system was best calculated for the purpose. This report was followed up subsequently by a visit, at Colonel Morant's instigation, of Mr. Riggenbach, the inventor of the Rigi system, to Coonoor, and his submission of detailed plans and estimates for construction of the short line, at a cost which would not have exceeded £20,000 a mile. A company was formed to carry out the work, but what with indifferent management of its affairs, want of liberal concessions by the Government of India, and a lack of spirit on the part of Neilgherry landowners, householders, and traders, who might have dispensed with any guarantee in view of the favourable statistics of traffic, the railway has not yet been started. It is not too much to say that had Colonel Morant's project been for the benefit of a hill sanatorium in the north of India, the trouble and pains that he took in this matter would not have been thrown away, as has hitherto been been the case. The Neilgherries would have had their railway ere this, as well as Darjeeling.

In his capacity as an architect Colonel Morant entered into the competition for the Municipal Hall and offices at Bombay, which opened in the year 1884, and his plans obtained the second prize of Rs. 3,000 in that competition, the successful competitor being Mr. Chisholm. The buildings as designed by him were to have

covered a space of 3,300 square yards; the hall was to have been 80 feet by 40 feet by 35½ feet in height; there were to have been two domes in the building, one dome 114 feet in height; and the total cost was to have been 5 lakhs of rupees.

Colonel Morant was elected an Associate of the Institution of Civil Engineers on the 5th of December, 1872.

ALEXANDER OGILVIE was born at Clocksbriggs, in the county of Forfar, on the 15th of February 1812. He died on the same date in 1886. His education was first conducted at the High School of Edinburgh, where at an early age he evinced that talent for figures, and acute comprehension of results which was one of his most marked characteristics through life, and which enabled him in future years to carry out very large works with success, even in seasons of great and universal depression. After studying at the High School for some years, Mr. Ogilvie graduated with honours at the Edinburgh University, and thence, determining to make England the stage of his active work, went into Cheshire to learn practical engineering under Mr. S. Fowls, M. Inst. C.E., Engineer to the Trustees of the River Weaver and Bridge-master of the County of Chester. It was here that he first became acquainted with the late Mr. Brassey, with whom ever afterwards he was, almost from that period, most closely associated. Each recognized in the other the existence of those sound qualities of which successful men are made, and it was at no distant date that a partnership was entered into that lasted through life, and was to the mutual advantage of both. The union of these two men was brought about in a curiously characteristic fashion. Both were invited to tender for a large contract, but before the day arrived for giving in the estimates, Mr. Brassey called on Mr. Ogilvie, and said, "It's no use making two bites of a cherry; let's go in together, or one of us retire." And so it was; and during the life of Mr. Brassey Mr. Ogilvie had him as a partner in all the works he engaged in. To the credit of both it may be here related that, almost without exception, every one of the numerous contracts jointly undertaken were financially successful. Averse to society, and strongly attached to his own home, he rarely mixed with his fellow men in the social sense, but he was ever willing to help with a generous hand those who needed aid: reticent and guarded in speech, he was a typical Scotchman of the best order.

The English railway contracts undertaken by Mr. Ogilvie, in

partnership with other contractors, were mainly in the various systems now grouped under the Great Eastern, and London and South-Western Railways; amongst the former may be named the Colchester and Ipswich, the Ipswich and Bury, the Haughley and Norwich, the Sudbury, Bury St. Edmunds and Cambridge, the Epping, and Dunmow Railways; amongst the latter the North Devon, the Portsmouth direct, and the Salisbury and Yeovil Railways. Outside of these, the Runcorn Branch Railway, on the London and North-Western system, with its important bridge over the Mersey, a portion of the Thames Embankment, and the Metropolitan Mid-level sewer, may be mentioned. The chief foreign works undertaken by him were the Mauritius, the Central Argentine, and the Buenos Ayres and Ensenada, Railways, and the Rio de Janeiro drainage. It may be of interest to state that Mr. Ogilvie executed over £10,000,000 worth of work, out of a total of over £30,000,000 tendered for, and that the actual practical control in the various partnerships fell very largely into his hands. He was elected an Associate of the Institution on the 7th of May 1850, and served as a Member of the Council in the Session 1864–65.

WILLIAM CHARLES RICKMAN, who was born on the 12th of January, 1812, met with instantaneous death on the 21st of June 1886, as the result of a carriage accident, in his seventy-fifth year. Mr. Rickman has special claim to notice from the fact that he was a son of Telford's executor, and the editor of the magnificent work descriptive of the labours of the first President of the Institution.

The subject of this notice was educated at Dr. Buckland's, Laleham, at Westminster School, and at Christ Church, Oxford, obtaining his B.A. degree in 1831; he also noviciated as an architect, having served a pupilage to Mr. Decimus Burton, the well-known architect, and had made the European travelling round of study; but, possessed of independent means, he never seriously followed the profession as a vocation. Before his school days he turned out a fire-engine and a reproduction of the Roman catapult. In 1834 he was engaged in an experimental enquiry respecting the best position for weight as regarded draught of vessels, in which no doubt he was in touch with his intimate ally, old school-fellow and friend, Froude. In 1836 he was stationed at St. Catherine's, Isle of Wight, as a volunteer, from being on very intimate terms with Mr. Walker, Past-President Inst. C.E., the Engineer to

the Trinity Corporation, who was then erecting the present ornate tower and dwellings, taking the place of the early tower on the Downs from the last being so frequently obscured by fog. These buildings, designed or worked out by Mr. M. A. Borthwick, are of a bastard castellated Gothic type, and Rickman from his education was well adapted to overlook the working out of their details. The buildings were founded on the Undercliff, a mass of rock of unusual size in the débris being selected as the foundation for the base of the octagonal tower. When the lantern was being fixed, and the keeper's dwellings were being slated, some ugly but minute fissures made their appearance on the landward side of the site of those buildings, and it was found that the tower had inclined slightly seaward. A careful survey was made of all the surface fissures, in which Rickman assisted, resulting in the adoption of surface contour drains to assist the drainage from the upper cliffs and convey it seaward around the flanks of the site. The drains were so far successful that, after half a century's usage, the works are intact. Here Rickman displayed that kindness and philanthropic spirit he afterwards showed in his own neighbourhood, by directing the studies and lending books to the more ambitious of the workmen employed by the contractors to the Trinity Corporation. In his own private circle, his intimacy with such men as Lefroy, the Secretary to the Speaker; the Rev. Cyril Page, the first incumbent of Christ's Church, Westminster; William Froude, M. Inst. C.E., and some others, who were all members of a social club, founded by them, is indicative of the man's character.

He passed a great portion of his middle life abroad. Marrying somewhat late, and settling down in Charles Kingsley's nook of Hampshire, and in his own parish of Lithanger, near Petersfield, he erected schools and devoted time to the education of the children of his fellow-parishioners, and to popular readings and addresses. The great advantages he had himself derived from superior educational facilities, combined with very engaging manners and a remarkably handsome presence, rendered him essentially effective in such endeavours, which, however, mainly emanated from very earnest religious feelings.

From 1848 to 1851 he was engaged on various naval investigations and improvements; the "American keel" amongst others, which he tested in Wexford harbour, where he assisted a friend in 1851 to start a yard for the manufacture of drain tiles. About this period he read a Paper before the British Archæological Association on the probable means employed to move the monoliths to and at Stonehenge. Several national industrial exhibits

were sent by him to the Great Exhibition of 1851 from Ireland, and numerous mechanical contrivances, in his house at Lithanger built by him in 1849, testify to his genius in this respect.

In a funeral sermon preached by the Rev. Evelyn Joseph Hone, M.A., Vicar of St. John, Deptford, at Empshot, Hants, on the Sunday following his death, passages occur referring to his absolute integrity, his invincible kindness, his indefatigable energy, and his faith; for although "he had his seasons of depression—seasons of anxiety and of fear—yet his faith never failed, and for the most part it was simply triumphant." An eloquent tribute was offered to his natural and acquired abilities, to his originality in mechanical contrivance, to his fine cultivated taste in art, to his knowledge of ancient and modern poetry, to his eminence as a reader from sympathy with author and audience, and to his grace in letter writing.

Mr. Rickman was elected an Associate of the Institution on the 24th of April, 1838.

SANCTON WOOD was born at Hackney, in the year 1815. His father, Mr. John Wood, who was a member of an old and prosperous Cumberland family, had, when a young man, quitted his native county to enter into business in London as a "Manchester Merchant;" from thence he married a Miss Harriet Russell, niece of the eminent painter, Mr. Richard Smirke, R.A.

Six children were born of this marriage, the youngest child and only son taking his distinctive Christian name from an uncle, Mr. Philip Sancton, a successful London Merchant, who had married his father's sister. As a boy, Sancton Wood does not appear to have received any great educational advantages so far as school life was concerned; he was first placed by his father at a small private school in Devonshire, and was afterwards transferred to a school in Birmingham presided over by Mr. T. R. Hill, the father of Sir Rowland Hill, C.B. This school was conducted on a somewhat unique "Voluntary" system, which attracted some attention at the time, and certainly had its measure of success, if Mr. Hill's own sons may be taken as examples. It is to be doubted, however, whether such a system could possibly produce high results with the majority of boys, and Mr. Sancton Wood was wont to declare that he fully entered into its spirit by volunteering to do as little as possible in the way of serious study; however this may be, it is certain that his general acquirements at the time he left school

failed to inspire his friends with any great hope of future success.

The lad was destined, however, to meet with greater advantages and more vigorous discipline in his professional education, and the connection with the Smirke family above referred to proved a most valuable influence in determining his career.

Having manifested a taste for drawing, he was, through his mother's influence, admitted into the office of his cousin, Sir Robert Smirke, R.A., who was then one of the leading London architects; from this office he was transferred to that of Mr. Sydney Smirke, R.A., who succeeded to his brother's practice. He remained with Mr. Sydney Smirke for several years after the expiration of his articles, and was engaged upon the drawings of many important works; amongst others may be mentioned the sketches of the designs for rebuilding the Houses of Parliament, which Sir Robert Smirke had prepared for Sir Robert Peel's government before the House of Commons decided in favour of an open competition. Whilst with Mr. Smirke, Sancton Wood became a student in the Antique School at the Royal Academy; subsequently he travelled on the Continent, spending considerable time in Spain and Portugal, collecting numerous drawings of the most important buildings he had seen, and making many sketches, all of which possess artistic merit.

In the offices of the two Smirkes he had been well drilled in the highest class of work, and his taste always bore the stamp of refinement which it there received.

About the time he commenced practice for himself, the railway system of these Islands was advancing by leaps and bounds, offering great opportunities to those architects who were so fortunate as to be employed, and Sancton Wood, partly by competition, partly by recommendation, secured a large share of the work.

In 1838 he was engaged by Mr. John Braithwaite, M. Inst. C.E., to design the buildings for the Eastern Counties Railway, including the old terminus at Shoreditch; his designs for the latter, however, were considerably modified, owing to financial difficulties. The first premium of £100 was awarded to him for his design for the station at Ipswich, and several of the stations on the Eastern Union Railway were designed by him for Mr. Peter Bruff, M. Inst. C.E. In 1845 his design for the terminal station in Dublin of the Great Southern and Western Railway was accepted in a competition in which sixty-five competitors were engaged, and this building, and nearly all the intermediate stations from Dublin to

Cork, were erected from his designs and under his superintendence. He was also architect to the Limerick Junction line, and to the Grand Racing Stand at the Curragh.

Mr. Charles Liddell engaged his services in the design and superintendence of several stations on two branches of the Midland and North Western Railways. In 1846 Mr. Wood obtained a premium of £100 for his design for the Blackburn Railway Station.

His work, however, was by no means confined to railway architecture; the streets and terraces known as Upper Hyde Park Gardens were laid out by him for Messrs. J. and C. Rigby, who built all the houses on the estate from his designs and specifications. He was also architect to the block of offices at the southwest corner of King Street and Gresham Street. His practice was now of a very extensive character, and it would be tedious to mention all the numerous buildings erected from his designs in London and in the provinces; they comprise, churches, schools, dwelling-houses, warehouses, offices, stables, and buildings of almost every class, many of them of considerable importance and excellence of design. In addition to the above works, Mr. Sancton Wood was surveyor to several building estates in different parts of London and the suburbs, amongst the most successful of which was the Lime Grove Estate, Putney; this estate was laid out by him and entirely covered under his superintendence, several houses upon it being built from his own designs.

Mr. Wood formerly held the appointment of District Surveyor of Putney and Roehampton, and for the last twenty-four years was District Surveyor of St. Luke's, Chelsea. In 1861, he was a candidate for the office of Superintending Architect to the Metropolitan Board of Works, and was only defeated by Mr. George Vulliamy by three votes.

His long and varied experience, coupled with his reliable judgment and rapid perception, eminently qualified him for the surveying branch of his profession, and he was very largely occupied with arbitrations, valuations and compensation cases; in later life his architectural practice was almost relinquished for this more profitable class of work.

Mr. Wood was a Fellow of the Royal Institute of British Architects, on the Council of which he served in 1850 and 1851, and a Fellow of the Institute of Architects of Ireland; he was also a Member of the Institute of Surveyors. He was elected an Associate of this Institution on the 4th of April 1848, and served on the Council in the Session 1857–58.

Although of too quiet and retiring a disposition to make the attainment of office a matter of ambition, still, like many other busy men, he did not shirk such voluntarily imposed duties. He was also a member of the Examining Board for District Surveyors, the duties of which post he performed up to the last.

For many years he was an active member of the Directorate of the Provident Clerks Assurance Company, in which he took a considerable interest. He was an eminently successful man in most things that he undertook, an able administrator with a clear, sound judgment, and a quick and accurate perception of facts. Although of a somewhat nervous and excitable temperament he was possessed of considerable vigour of mind, and great refinement and delicacy of feeling, and his unimpeachable integrity of character and courtesy of manner won him the respect and esteem of all men who came into contact with him.

He died at his residence at Putney Hill on the 18th of April, 1886, in the seventy-first year of his age, after an illness of two or three days.

⁂ The following deaths have occurred since the 31st of March last, in addition to those included in the foregoing notices:—

Members.

Adams, William (of Cardiff).	Stevenson, David.
Childe, Rowland.	Wade, William Burton.
Fulton, Hamilton Henry.	Williams, Edward.

Associate Members.

Catton, John Edward.	Murphy, James.
Cock, William Henry.	Newman, Frederick.
Hayward, Joseph.	Yeo, George Jope.
Morgan, Charles William.	

Associates.

Kelk, Sir John, Bart.	Price, Astley Paston.
Knight, John Peake.	

Information respecting the careers and leading characteristics of any of the above is solicited, to aid in the preparation of future Obituary Notices.—Sec. Inst. C.E.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Louisville Cements.

(Journal of the Association of Engineering Societies, 1886, p. 187.)

Fully 95 per cent. of the natural cement used in the district of St. Louis, U.S., is Louisville cement. The stone from which this is manufactured belongs to the Devonian formation, and its properties were first noted in 1828, in the course of construction of the Louisville and Portland Canal. The cement derived from the upper stratum is quicker setting and darker than that from the lower, and requires harder burning.

In 1870 (prior to which no record exists) the output was 320,000 barrels, and this has now increased to nearly 900,000. The chief markets are St. Louis, Chicago, Cincinnati, Pittsburg, Cleveland, and Detroit.

The general condition stated in specifications for this cement is that it shall have a tensile strength of not less than 40 lbs. per square inch when mixed pure, made into test-bars, and exposed thirty minutes in air and twenty-four hours or more under water. A series of nearly four thousand tests of the seven chief brands gave the following results:—

—	Exposed 30 Minutes in Air.			
	24 Hours under Water.	2 Days under Water.	3 Days under Water.	50 Days under Water.
	Lbs.	Lbs.	Lbs.	Lbs.
Highest tensile strength . . .	168·0	160·0	100·0	202·0
Highest average tensile strength of any brand	92·7	96·8	86·0	164·3
Average of all brands tested . .	72·2	78·7	73·2	150·6

P. W. B.

Results of Experiments with Impregnated and Natural Samples of Wood. By Dr. Boehme.

(Mittheilungen aus der Prüfungsstation für Bau-materialien, 1886, p. 26.)

The object of these experiments was to ascertain the relative effect on impregnated and natural pine wood samples of various treatment, corresponding as nearly as possible to that to which wood-paving is subjected.

The investigations were directed to the following points :—

(1) The effect of acids, urine, and liquid horse-dung, on impregnated samples.
(2) The effect of atmospheric influences on the same.
(3) The hydraulic absorption of impregnated and natural samples.
(4) Expansion in consequence of absorption.
(5) Resistance to bending } of impregnated and natural samples.
(6) Resistance to compression } of impregnated and natural samples.

The acids used were hydrochloric, sulphuric, nitric, and phosphoric, all with a strength of 10 per cent. The impregnated samples, after subjection for fourteen days to the various substances named, were found, on careful examination with a microscope, to be unaffected by them.

Atmospheric influences were artificially produced. The samples were (*a*) slowly heated in water to boiling-point, kept for some time at this temperature, and then suddenly cooled by plunging into cold water; (*b*) boiled half an hour in a 15 per cent. solution of salt, and frequently cooled suddenly during this time; (*c*) boiled half an hour in a 5 per cent. potash solution; (*d*) boiled half an hour in the same solution, with an addition of 1 per cent. sulphide of ammonia; (*e*) boiled half an hour in a solution containing 2 per cent. sulphate of iron, 2 per cent. sulphate of copper, and 10 per cent. of common salt. The samples were not injuriously affected by this treatment.

Impregnated samples of wood absorbed much less water than those in a natural condition.

The increase in volume, in consequence of the absorption of water, was less in the impregnated than in the natural samples.

The tests on the bending-strength of the samples showed that those impregnated were stronger by about 15 per cent. than the others.

The resistance to compression of the impregnated samples was greater by about 22 per cent. than that of the natural samples.

Before testing for absorption, all the samples were thoroughly dried.

The method of impregnation, at the request of the manufacturers, is not described.

In the original, all the detail results of the experiments are given in a tabular form.

G. R. B.

Recent investigations concerning the Dry-rot Fungus (Merulius lachrymans). By Dr. K. B. Lehmann of Munich.

(Gesundheits-Ingenieur, 1886, p. 359.)

This fungus[1] does not occur either on the growing timber or upon decaying wood in the forests themselves; it belongs entirely to the dwellings of civilized communities, and it is so susceptible

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[1] Minutes of Proceedings Inst. C.E. vol. lxxx. p. 419.

to the influence of air and light and of heat and cold, that it could scarcely exist in the forests of Northern Europe. It is very difficult to say where it originally came from, but at present it is introduced solely by the use of infected timber from old buildings; or possibly the spores, four millions of which would only occupy the space of a cubic millimetre, may be conveyed into new houses on the clothes, boots, or tools, of the workmen. Hitherto all attempts to cultivate the fungus from its spores have failed, and Professor Poleck, of Breslau, is the first observer who has succeeded in producing a vigorous growth of the merulius on fir timber. The mode of growth is explained by reference to illustrations, and certain peculiarities in the structure of the fungus which have been found in no other vegetation of the same kind, more especially the development of little side branches (*Aestchen*) from the buckle-cells are pointed out. Professor Hartig has shown that the fungus throws out broad tubular chains of cells, apparently destined for the conveyance of water to a distance; and he has proved that the mycellium of the merulius offers far greater resistance to drying influences than that of the common mildew. He states further that the fungus can only assimilate the mineral matter of the cell-walls of the timber when it is in contact with it, and that it is unable to extract the inorganic constituents of the wood cells from any distance. The component matters of the cell-walls—coniferin and cellulose—are absorbed, but the tannin and the wood-gum or resin appear to remain unattacked by the fungus. The albuminous matters contained in the cells are consumed, but where the supply of albumen is scanty the merulius appears to prey upon the decaying protoplasm of former growths of the fungus, so that in timber which has been strongly exposed to attack scarcely any traces of the mycellium are distinguishable. Analyses are given of the mycellium and of the spores, from which it would appear that while the barren mycellium is rich in insoluble phosphates of iron and of lime these salts are wanting in the spore-beds, and are replaced by enormous quantities of phosphate of potash. It was in consequence of the results of these analyses that Professor Poleck was induced to examine the ashes of timber felled in the winter and in the summer, and that he was led to assert that the summer-felled timber affords a better supply of nourishment to the fungus than that felled in winter, the former, as will be seen from the Table, being five times as rich in potash, and eight times as rich in phosphoric acid as the latter:—

ONE HUNDRED GRAMS of SOUND PINE TIMBER DRIED at 110° CENTIGRADE.

Yield.	Taken from a Pine felled in the Winter.	Taken from a Pine felled in April.
	Grams.	Grams.
In ash	0·19	0·22
Percentage soluble in water	7·89	24·08
Containing potash	2·67	11·57
„ phosphoric acid	0·76	5·85

Experiments which confirmed this view were conducted with blocks of timber enclosed in casks. In opposition to the theory of Poleck, a number of experiments carried out by Hartig are recorded. In the first place, Hartig shows that at the end of April the sap has not risen in the timber, and that no mineral matters can have been stored up in the wood-cells which were not present at the beginning of the winter; and that true summer-felled timber must, if anything, be poorer in mineral salts than that felled in the winter time. The analyses he made confirm this view, for he found in the ashes of the winter wood 8·42 per cent. of phosphoric acid, and only 5·89 per cent. in the summer wood. Moreover, the experiments of Poleck pointed to a necessity for phosphoric acid and potash to encourage the growth of the fungus, while Hartig insists only upon the presence of ammonia or potash-salts, and makes no mention of phosphates.

Hartig's practical experiments, which were carried out in a specially constructed cellar, were made both with pine and fir timber felled for the purpose. Small specimens of each kind of wood were enclosed along with wood containing live mycellium of the merulius in glass vessels, and also in contact with various materials, such as garden mould, sand, coal-dust, ashes, &c. They remained thus enclosed from the 8th of July until the 20th of December, and the condition of each sample was examined on the 6th of August and on the 11th of September. At the end of the experiment the loss in weight of the sound and of the infected wood was noted, also the loss in bulk, and the amount of moisture present in each specimen. These observations are set forth in numerous Tables, the general result being that both winter- and summer-felled damp fir and pine (the different kinds of timber behaved alike) lost equally in weight. When, however, dry winter-wood was contrasted with wet winter-wood the results were astonishingly different. In the case of fir, while the dry wood lost 11 per cent. in weight, the wet wood, as might be expected, lost 23·1 per cent.; but in the case of pine the loss on the dry wood was 13·3 per cent., while on the wet wood it was only 13·6 per cent. Comparative experiments with the heart timber in fir and pine as contrasted with the outside planks showed that while in fir the heart was destroyed more rapidly than the outer layers, the reverse was the case in pine. Very unexpected results have been obtained when the wood was in contact with the various substances already enumerated; and it would seem that clean sand is a worse material for filling in between the joists than a mixture of sand and plaster, while dry rubbish from old buildings takes a much better place than coal-dust. Numerous observations are given of the loss of the timber in bulk and weight, and of the nature of the changes which arise from the growth of the dry rot. On the subject of the injury to health caused by the fungus in houses, the present opinion is that positive proof is wanting. A long list of precautionary measures follows, setting forth the best known means of combating the spread of dry rot; and the Author cor

siders the effect of the different specifics and preservative solutions, of which creosote oil appears to be the best. Tests of various kinds with preservatives are recorded, but a general warning is given against trusting to any of these proposed remedies.

G. R. R.

Experiments with respect to the Dry-rot Fungus (Merulius lachrymans.)

(Gesundheits-Ingenieur, 1886, p. 471.)

Professor Dr. Meidinger states that Professor Poleck has discovered that the timber procured for him purporting to be winter-felled wood, was in reality raft-timber, floated down the river, and he has ascertained that timber which has been thus immersed is no longer liable to the attack of dry rot. So much so is this the case that in Alsace it is customary to specify that only raft-timber shall be employed. The water slowly dissolves out the albumen and salts, and thus deprives the fungus of the nutriment needful for its development. A French savant has found by experiment that whereas fresh sawdust, when buried in damp earth rots away in a few years, sawdust which has been soaked for some time in water, and has been thereby deprived of soluble matters, will remain in the ground under similar circumstances wholly unchanged, and only slightly tinged on the exterior with earthy matters dissolved from the soil.

G. R. R.

On Iron Bridges. By E. Ebert.

(Vierteljahrsschrift der Polytech. Vereins in München, 1886, II.)

This communication deals with the development of iron bridges from the time when cast-iron was largely used in their construction to the present day.

The results of the experiments of Wöhler on the fatigue of metals were calculated to shake the faith engineers had placed in iron as a material for the construction of bridges; the Author, however, is convinced that any structure of iron designed and erected on correct principles, in which only good iron is employed, and where the stress caused by the maximum load the bridge is to bear, is well within the limit of elasticity, will last for ever, provided also the formation of rust be prevented.

The iron used for bridge-construction on the Bavarian State Railway must possess a tensile strength of at least 320 tons per square decimetre (20·5 tons per square inch). The material used for rivets must be capable of being bent double, and a cylinder of height equal to two diameters must be capable of being worked

cold to half its height without, in either case, any cracks or signs of extreme distress being visible in the iron. Only cast-steel is used where steel is required. To prevent the formation of rust the iron is treated in the following way before being put together: It is dipped in dilute acid, washed in lime-water, well rubbed until clean, immersed in boiling-water; and when it has acquired the temperature of the water, it is taken out, painted with hot linseed oil and then with non-corrosive paint. As deteriorating agents, the vibrations and sudden shocks due to a live load are second only, in importance, to the formation of rust. The Author condemns the practice of connecting the rails rigidly to the main girders; an elastic medium, such as wooden sleepers, ought to be interposed. The Author considers it of vital importance to adopt some means of ascertaining the extent to which a bridge is deteriorating. The increase in the permanent deflection is not a reliable criterion, as even serious defects in the bracing would not be readily recognizable by this method. The Author suggests that means of examining every part of the bridge without danger to life be considered in the design; that the examination of a bridge be undertaken by specialists only, and that a record be kept of every incident subsequent to the opening of the bridge for traffic.

The Paper is accompanied by numerous diagrams illustrative of the various forms of girder which have been designed, and of several methods of measuring the deflection of a bridge when testing it.

E. C. S.

Report on the Results of the Trials of the Bridge over the Rhine near Rhenen.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1885–6, p. 89.)

The bridge consists of three openings of ninety metres span, and of four openings of 45 metres. The distance between the supports in the large openings is 93·55 metres; of the smaller ones, 47·52 metres. In the larger openings the top-girder booms are curved to the arc of a circle; in the smaller openings, top and bottom booms are parallel.

According to the specification, the trial-loads for the large openings were to be 4,000 kilograms per lineal metre, and for the smaller spans 4,300 kilograms per lineal metre.

During the trials the following points were specially investigated:—

a. The deflection in the centres of all the girders.

b. The deflection on one of the larger spans at distances from the supports of one-fourth the span.

c. The lateral deflection of the lower beams in the large spans, and of the top beams on the smaller spans.

d. The lateral movements in the main girders at the end verticals on pier 3 and the southern abutment.

e. The increase in length of the bottom flanges of all the spans.

f. The increase in length of the collective longitudinal floor-girders in the three longest spans.

g. The deflection of four longitudinal floor-girders of one large span, and of one cross-girder of the large spans.

h. The radial movement of the ends over the supports on pier 1, and of the cross-girder *b* of the first opening round the axis of support in the bottom beam.

i. The lateral deflection of a vertical.

k. The strains in the top and bottom beams, diagonals, and verticals, and in four longitudinal floor-beams of one bay of the north span of 93·5 metre.

The observations as to deflection were made by direct measurement, and by means of spirit-levels. In the experiments *k*, the tension or extension measuring instruments of Frankel and of Manet were used.

The results of the observations are collected in thirteen Tables, and several drawings accompany the Paper.

H. S.

Old Bridges under New Loads.

(Journal of the Association of Engineering Societies, 1886, p. 159.)

With the increased speed demanded by the development of traffic in late years, and rendered practicable by the more efficient control obtained by the adoption of automatic brakes, both locomotives and cars are now constructed of considerably greater weight than was customary when the largest percentage of existing bridges was erected. In freight and passenger locomotives the increase in weight during the last ten years has been about 50 per cent., and in cars nearly 80 per cent. Bridges built for standard loads in 1876 are now, therefore, overstrained from 25 to 50 per cent. in different members.

This is in relation simply to dead load. With regard to the mechanical effect of moving load, expressed by the formula

$$E = 2 \frac{v^2}{2g} W \sin . a,$$

(E being directly proportional to the square of the velocity) where the speed is doubled, the mechanical effect is multiplied by 4. With a speed increased within the last ten years by nearly 50 per cent., and the increased dead weight of rolling-stock, the strain on bridges designed under the old conditions is now multiplied by 3.

P. W. B.

Metal Viaducts in Large Spans. By L. Leygue.

(Annales des Ponts et Chaussées, vol. xi., 1866, p. 304, 1 plate and 17 woodcuts.)

Recent practice has given the preference to straight girders, over arches, for metal viaducts crossing deep valleys, owing to the saving of material, and facility in erection. Assuming, then, the superiority of straight girders, it is necessary to determine whether the piers shall be of masonry or metal; what shall be the number of spans; whether the bridge shall be of iron or steel, and what shall be the method of erection. As regards the piers, it is admitted that masonry is preferable to metal up to heights of about 130 feet; the advantage of masonry above that height depends upon its resistance to crushing; but as hard stone is generally found in country rugged enough to require high viaducts, the use of metal piers may be considered exceptional. The cost of a viaduct, for crossing any given valley, increases with the number of piers, and decreases in proportion to the number of the spans; and it is found, taking the special case of a valley 1,110 feet wide, and piers averaging 262 feet in height, that four spans would be the most economical; but as a pier in the lowest point of the valley would be both unadvisable and unsightly, five spans would be the best. The use of steel instead of iron for large spans offers the following advantages; the height of the girders can be reduced in the ratio of 0·859, which is of importance for heights of 33 feet and upwards; the sectional area of the flanges can be reduced in the ration of 0·812, and of the trellis-bars in the ratio of 0·693; and the weight of the roadway can be reduced two-tenths. Moreover, as there is a larger margin in steel between the safe load and the limit of elasticity, those portions which are overstrained in rolling out the girder will be in less danger of taking any permanent set. Erection by rolling out becomes very difficult for spans exceeding 330 feet, and it is expedient for such spans to adopt semi-continuous girders with a central junction. Formulas and diagrams are used in the process of arriving at the above conclusions; and the article concludes with an application of the formulas to the design of the viaduct of Viaur.

L. V. H.

Tests of Vehicle-Wheels. By H. M. Dubois.

(The Journal of the Franklin Institute, July 1886, p. 36.)

Several of the largest manufacturers of wheels in the United States, in view of the numerous varieties of wheels in use, combined to institute a series of scientific tests of wheels, in order to test their carrying capacity and their respective merits. The Author conducted these tests.

An assortment of wheels was received, uniform in size and

general dimensions, representing all the kinds of vehicle-wheels in common use. It was decided that each specimen should be tired as for regular travel, and subjected first to a test for the weight required to dish the wheel backwards to the extent of 1¼ inch, which is the extreme limit in practice when the tire ceases to be a factor. The pressure was then to be removed, and the reaction noted. By a second application of pressure the wheel was to be tested to rupture, or until it became wholly useless. The testing-machine of Messrs. Riehlé Brothers was employed for this purpose, the wheel being placed face downwards on the face-plate of the machine, taking a bearing at the rim; and the load being applied through a suspending bolt to the nave of the wheel. A special face-plate was prepared to take wheels as large as 4 feet in diameter.

The wheel having a "banded wood hub," or nave, is the most popular for fine carriage-work. Into a wooden centre radiating spokes are driven, supporting the ring or felly, the whole bound together by a metal band or tire. Wheels of greater strength were designed, dependent upon the mode of placing the spokes in the hub. In the Sarven hub, a series of spokes are driven into a small wooden core, and mitred to form a solid arch of wood around this core. Against the back and face of these spokes a metal flange is forced by hydraulic pressure and securely riveted, forming an apparently indestructible wheel. In the Warner wheel, the spokes are driven through a metal mortise-ring into a wooden hub —evidently a stronger construction than that of the banded wood hub wheel. This wheel, though not so rigid and stiff as the Sarven wheel, is open, in common with this wheel, to the objection that the vibration due to rapid motion is conveyed to the carriage-body, and that there is more rapid wear of the tires and rims than in the earlier wheel. After years of trial, both those systems of wheel have been condemned for carriage-wheels, whilst they steadily increase in popularity as wheels for conveying merchandise and heavy burdens.

The latest form of wheel for carriage-work, invented by Mr. Jared Maris, is called Brown's shell-band wheel, or the "B.S.B." wheel. It consists of a metal shell round the hub, having internal ribs which enter the grooves in the hub, and perforated to receive the spokes, which enter the hub of their full undiminished section.

The order-numbers of the tests, and the designation of the wheels tested, with the number of spokes and the original dish, are as follows. The tests Nos. 1 to 8 were for strength of dish; Nos. 9 and 10 were made to determine the comparative holding powers of tenons.

It is remarkable that all the wheels lost their original dish, and the spokes became "straight," under a load of 300 lbs.; excepting No. 6, which became straight under a load of 250 lbs. When loaded for 1¼ inch of backward or reverse dish, Nos. 1, 4, 5, 6 and 7, bore a load of 1,300 lbs. Under this load No. 4 yielded $1\frac{3}{8}$ inch back, and No. 8 yielded $1\frac{7}{8}$ inch. The B.S.B. wheels,

Nos. 1 and 5, were the only wheels which recovered their original dish when released; the others fell short of their original dish.

No. of Tests.	Style of Wheel.	Number of Spokes.	Original Dish.
			Inch.
1	B.S.B.	14	$\frac{1}{2}$
2	Sarven	16	$\frac{5}{8}$
3	Banded wood hub	14	$\frac{3}{8}$
4	Wood hub	14	$\frac{11}{32}$
5	B.S.B.	14	$\frac{1}{2}$
6	Sarven	16	$\frac{1}{2}$
7	Maris socket	14	$\frac{1}{2}$
8	Warner	14	$\frac{1}{2}$
9	Banded wood hub	14	$\frac{1}{2}$
10	Band wood hub / Compressed tenon	14	$\frac{1}{2}$

For the second course of tests—to destruction—the following were the results.

—	Maximum Pressure.	Backward Dish.	State of Wheel.
No.	lbs.	Inches.	
1	2,400	4	Returned to original dish, sound in every part.
2	2,400	4	All the spokes drew from hub.
3	2,000	4	Two spokes started from hub; one split.
4	1,950	$3\frac{1}{8}$	Wheel collapsed; hub split.
5	2,600	$5\frac{3}{4}$	Two spokes broken in barrel, but sound in hub.
6	2,650	4	Rivets pulled and spokes broken.
7	2,200	4	One spoke started.
8	1,550	$2\frac{1}{8}$	One spoke broke, and eight drew from hub.
9	..	5	Three spokes drawn from hub, and one started.
10	..	5	Eleven spokes drew from hub.

No. 5 was afterwards placed on supports under the spokes 12 inches from the hub. It resisted a load of 3,750 lbs., when one spoke was drawn out.

It appears that the B.S.B. wheel No. 1 was the only one which withstood all the stress, and retained its elasticity unimpaired.

D. K. C.

Resistance of Trains on Railways. By — Desdouits.

(Annales des Mines, 8e serie, vol. viii., 1885, p. 481.)

In this article the Author gives the results of a long series of experimental investigations of the resistance of locomotives and trains on railways.

The resistances due to the rolling of the wheel-flanges and the sliding of the axles in the bearings are taken together as the resistance to rolling, the one and the other element being taken as proportional to the load, and the joint resistance being taken at so much per ton. But the resistance of the atmosphere varies in wide proportions, not with the load, but with the forms and the grouping of the vehicles. Besides, the element of atmospheric resistance considerably preponderates in the composition of the total resistance—for high-speed trains at least.

From a geometrical point of view, trains of all kinds belong to one of two classes—passenger-trains and goods-trains. The first are regularly and compactly formed, the second are irregular and more widely connected. The elementary train, as it is called—engine, tender, and brake-van—is the first submitted to experimental investigation. For resistance at very low speeds, when atmospheric resistance is a minimum and may be neglected; and afterwards at high speeds, when the law of atmospheric resistance may be determined. For each experiment the engine is in steam, and the regulator is slightly opened, so as to obtain a conveniently low initial speed of from 3¾ miles to 5 miles per hour (6 to 8 kilometres); then steam is shut off, and the stopping of the engine by its own proper resistance is observed. The four series of engines in regular service have been submitted to experiment, of which the leading features are here tabulated:—

Designation of Locomotive.	Axles.	Wheels. Diameter.		Cylinder.		Weight.		
				Diam.	Stroke.	Engine.	Tender.	Total.
		Ft.	Ins.	Inches.	Inches.	Tons.	Tons.	Tons.
1. High speed	3 axles, 2 coupled	6	7½	17·3	25·6	36	16	52
2. Mixed .	3 „ coupled	4	11½	16·5 18·5	23·6	32	16	48
3. Goods. .	3 „ „	4	4	17·7	25·6	36	16	52
4. „ . .	4 „ „	4	2	21·3	26·0	54	16	70

The cylinders of all these engines are outside. The high-speed engines have the Stephenson link-motion, with valves of two kinds—ordinary slide and cylindrical. The mixed engines have ordinary slides. The three-axle goods engines have the same, and the four-axle engines have cylindrical valves.

A dynamometer of special construction, with pendulum movement, was fixed on the platform of the tender. The regulator was gently opened, so as to give a speed of about 6 miles per hour; then suddenly closed, when the engine was left to come to a state of rest without the use of the brake on the tender. A diagram of uniform resistance was described. The observation was repeated three or four times backward and forward on the same piece of line, making a passage of from 110 yards to 160 yards. According to another system of observation, the time taken for each revolu-

tion of the driving-wheels in the course of the run was noted, and thence the speed and the retardation were calculated.

It is of essential importance that the state of the experimental way should be, if not perfect, at least in average condition as for a portion of the main line. This condition is often but imperfectly realized in stations and goods yards. The locomotive also should be in at least average good order, working freely, stuffing-boxes not unduly tight, bearings free, lubrication good, tender-brake quite clear. The engine should have made a run since being lighted up, in order to bring all the moving parts into a proper state of lubrication, and to their normal temperature. An engine cold, and taken direct from a state of rest, though well oiled, usually has a surplus of resistance of from 30 to 50 per cent. Newly-repaired engines have shown nearly double the normal resistance. The state of the atmosphere affects the resistance. A head wind of 16 feet per second would suffice to double the resistance at a speed of 5 miles per hour. The resistances are deduced from velocities diminishing from 5 miles to 2½ miles per hour.

From the detailed Tables given of the observed resistances of the engines tried, the following summary of the resistances in lbs. per ton of gross weight of engine and tender has been prepared :—

Designation of Engines.	Resistance per ton of Engine and Tender.		
	Slide-valves. Stephenson link.	Cylindrical Valves.	
		Stephenson link.	Walchaërts Gear.
	lbs.	lbs.	lbs.
1. High speed . . .	6·94	..	5·82
2. Mixed	8·06	8·06	..
3. Goods (3-axle) . .	10·53	..	..
4. „ (4- „) . .	..	..	9·18

It appears that the engines fitted with cylindrical valves and the Walchaërts gear have a marked advantage over those of the ordinary type of gear. Comparing the two high-speed engines, there is an advantage in reduction of resistance with the modified gear of 1·12 lb. per ton, or 16 per cent. Again, the four-axle goods engine, having the modified gear, has 1·34 lb. per ton less resistance than the three-axle goods, although the four-axle engine has the smaller wheel, and the larger dimensions of cylinders and mechanism. The mixed engines have equal resistances of about 8 lbs. per ton. In this case the transformation was only partial, and with the introduction of the cylindrical valves the old

Stephenson gear was retained, and it was constructed with a return movement. The diameter of the cylinders also was augmented. These causes of supplementary resistance are compensated by the modification of the valve gear.

The resistances above announced are noticeably less than those which are generally assigned to like engines according to earlier experiments. The difference probably arises, for the most part, from the higher speeds at which these were made.

Resistance of the Machinery of Locomotives.—Experiments were made with a high-speed engine, a mixed engine, and a four-axle engine. For each experiment an auxiliary engine in steam was employed to get up the speed of the engine on trial—from 4 to 5 miles per hour—afterwards putting on its brake. The retarded movement of the engine was then noted. The reverse movement was given by a second auxiliary engine. Each engine in working order was also tried in steam. The results are here tabulated as follows:—

MACHINERY-RESISTANCE.

Designation and Conditions.	Resistance per Ton.	Total Resistance.
	lbs.	lbs.
1. High-speed engine, with flat slide-valves, entirely mounted, in steam (weight, including tender, 52 tons)	7·17	373
The same engine, connecting-rods, valve-gear, and coupling-rods dismounted	5·26	274
Say, for all the movable pieces	1·91	99
2. Mixed engine, with flat slide-valves, entirely mounted, in steam (weight, including tender, 48 tons)	8·06	387
The same engine, connecting-rods and valve-gear dismounted	5·04	242
Say, for the mechanism	3·02	145
The same engine, with the connecting-rods, coupling-rods, and valve-gear dismounted	4·93	236
3. Goods engine, 4-axles coupled, with cylindrical valves, entirely mounted, in steam (weight, including tender, 70 tons)	8·96	627
Same engine, connecting-rods and valve-gear, dismounted	6·94	486
Say, for the mechanism	2·02	141
Same engine, connecting-rods, coupling-rods, and valve-gear, dismounted	6·94	486

These results show that the mechanism absorbs from 27 to 22 per cent. of the whole resistance of the engine. For the mixed engine and the four-axle engine the resistances are nearly the same. The influence of the coupling rods is scarcely appreciable.

Resistance of the Tender alone.—The results of trials made with tenders separated from the engines give from 5·60 to 6·27 lbs. per ton for resistance, ranging about the same as that of the engines or carriages.

Resistance of Passenger-Carriages and Vans.—From the results of trials with trains of seven and eight vehicles, lubricated with colza oil and with mineral oil, the resistance was at the rate of 3·47 lbs. and 3·58 lbs. The wheels were 3 feet 5 inches in diameter, with journals 3½ inches by 7 inches, and loaded to 4 and 5 tons respectively per axle. The temperature during the trials was 59° Fahrenheit.

Resistance of Goods Wagons.—A train of thirty wagons, weighing in gross 300 tons, was tried. It was lubricated with colza oil, having wheels and journals like those of the carriages. The resistance of the engine, tender, and train—the engine and tender weighing 70 tons—was at the rate of 4·93 lbs. per ton, or for the train separately 4·10 lbs. per ton.

It is concluded generally for all sorts of vehicles, under conditions of lubrication like the vehicles tested, that a resistance without speed of from 3·36 to 4·03 lbs. (1·50 to 1·80 kilograms per tonne) per ton may be accepted, with an extreme limit of 4½ lbs. per ton. Greater resistances than these arise from defective lubrication or atmospheric resistance.

Resistances at high speeds: Atmospheric resistance.—Experiments were made on the resistance of the air to flat boards suspended laterally from a train, movable on axes and counterweighted. The train was run at increasing velocities, and the instant was noted when the resistance of the air preponderating caused the lifting of the weights and reversal of the board. It was deduced from experimental results that (1) the resistance on a surface 1 decimetre square (3·94 inches square) in absolutely calm weather, at a speed of 44½ miles per hour, amounted to 0·52 kilogram, or 1·14 lb., being at the rate of 106 lbs. per square foot. For other velocities the variation of resistance is sensibly as the square of the speed; and, within practical limits, the extent of the surface does not sensibly affect the coefficient of resistance.

The resistance to pressure may be reduced one-half by the adaptation of angular prows. A locomotive was fitted with angular prows on the smoke-box, buffer-beam, foot-plate fence, and other parts. The back of the tender was fitted with an angular tail-piece, and the wheel-spokes were covered in with sheet-iron. The resistance at a speed of 43½ miles per hour was, by means of these fittings, reduced 9 lbs. per ton. This engine thus fitted was kept on regular duty for a period of six months, working omnibus trains. The results compared with the average results from four engines of the same class in ordinary condition were as follows—

	Average Tonnage.	Consumption per Mile.
Four engines, in average condition . .	93 tons	22 lbs.
Modified engine	94 „	19 „

showing an economy of about 14 per cent. in favour of the modified engine.

The Author proceeds to develop formulas for the resistances of engines and trains at high speed. He recognizes the principle of the variation of all the resistances as a whole as the square of the speed.

D. K. C.

Way, Works, and Working of Railways.[1]

(Congrès des Chemins de Fer. Compte rendu Général, vol. i. 1886.)

The object of the Railway Congress which met at Brussels, August 8 to 15, 1885, was to aid in the amelioration and development of improvements in the construction and the working of railways; by the free discussion of questions on the way and works, traction, and material, working, and questions of a general character.

The first question related to types of metal, permanent way. Mr. Bricka (France) stated that transverse metal sleepers were in use on railways in Germany, Holland, and Switzerland, as follows:

—	Companies.	Length of Lines.	Total Length of Way.	Length of Way laid on Metal Cross-Sleepers.
		Miles.	Miles.	Miles.
Germany	9	8,644	14,758	1,806
Holland	4	1,250	2,083	181
Switzerland	4	1,026	1,530	49
Totals . . .	17	10,920	18,371	2,036

At the end of 1883, the total length of way laid in transverse metal sleepers amounted to 2,500 miles. One of the Swiss companies—the North-Eastern Railway of Switzerland—has definitively adopted transverse metal sleepers for new way and for renewals. Longitudinal metal sleepers have been laid in Germany, but they are being gradually abandoned.

Transverse metal sleepers weighing 1 cwt. have proved to be quite satisfactory. Sleepers weighing 77 pounds were tried at first, but they, as well as others weighing 88 pounds each, proved to be too light. On a few lines, much heavier transverse sleepers

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[1] The original is in the Library Inst. C.E.

are used. For instance, on the State Railway of Wurtemburg, sleepers of 128 pounds each are used. But the great majority of German and Dutch engineers consider that sleepers of 112 pounds each are sufficient; and that with them a perfectly steady way can be laid and easily maintained.

Mr. Kalff (Holland) stated that metal sleepers laid down twenty years ago were in perfect condition. The metal sleeper acted best on firm ground. Thus, on the Liége-Limbourg line, there were twenty thousand metal sleepers which had not been touched for twenty-two months, and the way continued in a most satisfactory condition, working trains at a maximum speed of 38 miles per hour.

Faults of construction in iron sleepers were eliminated in those made of steel, which were free from the liability to split and break incidental to iron sleepers.

Considerable discussion took place on the practical methods which had been proposed for comparing, with regard to cost of construction and working expenses, different projects for a railway embodying different conditions of plan and profile.

Then follows a discussion of the principles to be observed in the construction of rolling-stock, in view of facilitating and regulating exchanges. Mr. Hubert, the reporter on the question, begins with an exposition of the difficulties which, since the origin of railways, had existed in the way of exchanges of material between neighbouring railway-systems. Mr. Dietler, delegate from the conference of Berne, stated that the conference had been occupied principally with the dimensions to be settled for the rolling-stock for free exchange; of which one of the most important was the space between the wheels, which must correspond with the gauge of the way.

On the wide question of the reduction of the working expenses, Mr. J. Dejaer, and Mr. De Busschere, submitted an elaborate report ending with a series of thirty-three questions, bearing on the proportions and details of construction of the way and the works, engine-mileage, quantity of carriage and wagon stock; cost of fuel and lubricants; working secondary lines; speed in passing through junctions; gas-lighting and electric-lighting of trains; continuous brakes, marshalling of trains, &c. Mr. Banderali drew attention to the great importance of matching the steel used for the rails with the steel used for the wheel-tires. They should be of the same quality; and he adduced many cases in which, whilst the rails were of hard steel, the tires were of a soft quality of steel, and were worn out in a comparatively short time. The special point, he maintained, was to ascertain what ought to be the qualitative relations between the rail-steel, and the tire-steel. A resolution was adopted recommending a thorough investigation of the question. Cylindrical *versus* conical wheel-tires, were discussed, with the usual diversity of opinion. The substitution of cylindrical tires for conical tires on the old four-wheel carriages with a short base, had been found by Mr. Middelberg (Netherlands)

to be of great advantage in steadying the motion of the carriages at high speeds.

Very full Reports of the discussions are given in this volume, of 600 pages.

D. K. C.

The Large Retaining-Walls of Cournion, La Bastide, La Forêt, and Cerbère.

(Le Génie Civil, vol. ix., 1886, p. 145, 4 woodcuts.)

Important improvements in the construction of retaining-walls have recently been effected on the Southern Railway of France. The retaining-walls of Cournion, La Bastide, and La Forêt are on the railway from Mazamet to Bédarieux, already partially opened, and to be completed in 1887. They have all been built on a specially economical type, consisting of a sloping face-wall with nearly parallel faces, and strengthened at the back by triangular counterforts, extending out to or beyond the amount of overhang. The space between the counterforts is filled in with dry rubble walling, or with well-punned earth brought up in layers 8 inches thick. By this means a prism is formed behind the face-wall, exerting no thrust, and of which the weight and adhesion to the counterforts increase the stability of the wall in proportion as the batter of the face-wall is increased; also the thrust of the soil is thrown against the side-faces of the counterforts, and the cost of the masonry is reduced. In fact, as the batter of the face-wall is increased, the resultant pressure of the earth is reduced; and the necessary increase of the counterforts and of the backing is more than counterbalanced by the reduction in thickness of the face-wall, and eventually the thickness of the face-wall might be theoretically reduced to nothing, and serve only for protecting the surface at the back, resembling then the consolidation of cuttings by transverse buttresses. The Cournion wall retains an embankment of hard limestone; it varies in height from 5 feet to 62¼ feet, and has a length of 1,390 feet. At the highest portion, the wall has a thickness of 4½ feet at the top; the face-wall has a batter of 1 in 5 at the back throughout, and a batter in front of 1 in 5 for 30 feet down, and 1 in 3 below; and the counterforts are placed 19 feet apart, and are 4½ feet thick. The intervals between the counterforts are filled with limestone laid by hand. The mean thickness of this wall is 7¾ feet, whereas the usual formulas would indicate 11½ feet as the proper thickness, so that the new type effects a saving of about one-third. The Bastide wall, 133 feet long and from 18 to 24 feet high, has a face-wall 1 foot thick at the top, with a batter of 1 in 4 in front, and 1 in 4½ at the back; and its counterforts, 1⅔ feet thick, are 16⅔ feet apart, with an intermediate backing of dry rubble. Its average thickness is 1 foot 10½ inches, instead of 6¼ feet as indicated by formula; so

that the large saving of over two-thirds has been accomplished in this instance. The Forêt wall, 262 feet long and 16½ feet high, supports an embankment of schistose and gneiss rock; its face-wall has a batter of 1 in 5, and a uniform thickness of 3¼ feet; and its counterforts are 13 feet apart, with intermediate backing of the materials of the embankment laid by hand or with a hammer. Its mean thickness is 3 feet 8½ inches, as compared with the theoretical thickness of 5 feet 7 inches, affording a saving of one-third. The Cerbère wall, built for the Southern Railway at the Spanish frontier, is both a retaining-wall and a two-storied viaduct; it has a total length of 1,755 feet, of which a central portion, 1,010 feet long, is arched, and the rest at each end is solid. It is from 59 to 75½ feet high, and the piers of the viaduct are 39¼ feet apart; it contains 39,000 cubic yards of masonry, and its contract price was £40,000. The front of the viaduct faces the sea; and the back supports the embankment, which, taking its natural slope, rests upon the lower story of the viaduct, its foot being maintained by a dwarf-wall on the front face; and below, the slope is steepened by dry stone pitching, quarried from the neighbouring rocks, so as to reduce, as much as possible, the width of the viaduct.

L. V. H.

Successive enlargements of the St. Lazare Station at Paris.

(La Génie Civil, vol. ix., 1886, p. 196, 1 woodcut.)

The St. Lazare station is the oldest in Paris, and was built for the St. Germain Railway, opened in 1837. Five plans of the station, in 1837, 1842, 1854, 1867, and with the present works completed, respectively, indicate its gradual growth. A temporary station was erected in 1837; and it was only in 1842 that the station abutting the Rue St. Lazare was opened for traffic. In 1843, it had to be enlarged to accommodate the new Rouen Railway, which joined the St. Germain Railway at Colombes. The Brittany Railway, coming by Versailles, also ran into the St. Lazare station, which was thus used by three distinct companies. These companies were amalgamated into the Western Railway Company in 1855, when the large Pas-Perdus hall was built, which was enlarged in 1867. The lines were first roofed over in 1847; and an important enlargement was effected in 1854 for the new Auteuil Railway, and another in 1867 for the railway round Paris; and the tunnel under the Place de l'Europe was converted into an open cutting in 1865. Eleven railways come into the station, and the Moulineaux and Metropolitan lines will soon be added. Two hundred trains leave, and as many enter the station per day. The number of passengers using the St. Lazare station was about twenty-five millions in 1885, two and a half times that of the Est-Bastile station, the next most frequented station in Paris; whilst the six other termini of Paris together, including

the Est-Bastile, only accommodated thirty-four million passengers in 1885. The new station works, in course of construction, are described with illustrations in the preceding article by Mr. E. Boca. Their cost, exclusive of machinery and hydraulic appliances, is estimated at £110,000; and they will provide twenty-five lines of way alongside platforms, instead of eighteen as at present. The total cost of the new works is estimated at £144,600.

L. V. H.

The Metropolitan Railway of Paris. By MAX DE NANSOUTY.

(Le Génie Civil, vol. viii., 1886, pp. 382 and 400, 1 plate and 4 woodcuts.)

A concession has been granted to Mr. Christophle, Governor of the Crédit Foncier, for the construction of a metropolitan railway in Paris, under the direction of the State, and in accordance with the scheme submitted to and approved by the Chambers at the instance of the Minister of Public Works. The railway comprises four distinct lines, namely, an inner circle and three transverse lines. The inner circle consists of a continuous line of about 12¼ miles, from 1¼ to 3 miles inside the suburban railway encircling the outskirts of Paris, to be constructed partly on viaducts, and the remainder, half in tunnel and half in open cutting. It will cross over the Seine near the Champs de Mars, and also above the Austerlitz bridge; it will pass close to the stations of the Northern, Vincennes, Lyons, Orleans, and Western Railways, being connected by junctions with these railways, and also with the outer circle; and it will pass under the Trocadéro and the Place de l'Etoile. One of the transverse lines, starting from the St. Lazare station, and passing near the Opera and the Drouet cross-roads, joins the inner circle close to the Northern Railway station; it is 1¾ mile long, and will be mainly on viaduct. A second line, starting from a junction with the first at the Drouet cross-roads, passes through the heart of Paris; and going near the great Boulevards, the Post-office, the market-place, the Hôtel de Ville, and the Bastile, terminates in a junction with the inner circle at the Vincennes station. It is about 2⅝ miles long; and it is designed for four lines of way, and to be on a viaduct throughout. It will enable travellers by the Paris, Lyons, and Mediterranean, the Orleans, and the Vincennes railways, to reach the centre of Paris. The third transverse line runs nearly north and south, from the Place de Strasbourg to Place Denfert-Rochereau, joining the Strasburg Railway at the northern end, and the Sceaux Railway at the southern end; and it forms two junctions with the inner circle near Cluny. It is to be underground throughout, and will pass under the Seine at the Palais de Justice; and its total length is four miles. The sharpest curves on the railway are not to have a less radius than 7½ chains; and the steepest gradient is fixed at 1 in 50, except for the portion dipping under the Seine, where the maximum gradient will be 1 in 33 for rather less than

a mile. All the proposed lines and stations are clearly indicated on the plan, together with the proposed junctions with all the railways converging to Paris. Twenty-eight of the stations will be on viaduct, fifteen in open cutting, and twenty-one underground; and the stations will be about 550 yards apart, on the average, which is the minimum radius of attraction of a metropolitan station as indicated by the existing means of locomotion.

The works are to be executed in two separate sections. The first section comprises the inner circle, the transverse line between the St. Lazare station and the Place Roubaix station close to the Northern Railway station, and the underground line between Place de Strasbourg and Place Denfert, having a total length of 18 miles; and these lines are to be completed in time for the Exhibition of 1889, at an estimated cost of £8,400,000. The second section, $2\frac{3}{5}$ miles long, passing through some of the most valuable parts of Paris, is estimated at £8,600,000, and will be commenced directly after the close of the Exhibition. To these estimates for works and land, however, have to be added £2,000,000 to defray the interest on capital during construction, and preliminary and general expenses, raising the cost of the first section to £9,400,000, and of the second section to £9,600,000, and making the total estimated cost £19,000,000. The State guarantees interest at the rate of 4 per cent. on the £2,000,000, and $4\frac{1}{4}$ per cent. on the £17,000,000 for works, or a yearly amount of £800,000; but during the earlier years, when the first section alone will be open, the guarantee will be only £434,500 per annum; and the advances made under this guarantee will be repayable as soon as the net receipts of the company exceed the guaranteed revenue. As more than 50 per cent. of the population will be within a radius of 550 yards from the several stations, and 300 million persons are transported annually in Paris by the various means of conveyance, and assuming that the number of travellers is proportional to the number of inhabitants, the number of passengers on the metropolitan railway would be 150 millions. Some, however, of the anticipated increase of traffic from the formation of this railway would flow into parts of Paris not served by it, so the number of passengers may be reduced to 100 millions. Now the large railway companies have agreed to form junctions with the metropolitan railway, to run their trains over it, and to pay a minimum yearly toll of £280,000 for the passengers they bring on to the line. Assuming the number thus brought on at 30 millions, there would remain 70 million passengers, reckoned to pay each at least 1·9*d*., or about £560,000 altogether in the year, affording a total of £840,000 gross receipts. Deducting £200,000 for working expenses, the net revenue would be £640,000, leaving only £160,000, at the most, at the opening of the whole railway, to be provided by the State, and which probably, with the increase of traffic, will cease to be required at all after a very few years.

L. V. H.

On the formation of a Cultivated Region along the course of the Trans-Caspian Railway. L. BELIAVIN.

(Ingener, St. Petersburg, 1886, p. 782.)

The Transcaspian Railway, starting from Mehailoff Bay, follows the northern slope of the Kopet Dag hills, and passes through Kasil-Arvat, Aschabad, Dushak and Merv. The section to Aschabad is finished, the earthworks are completed as far as the terminus, so that the entire line may be opened during March of the present year.

One of the chief difficulties which beset the undertaking was the want of water, but by various means it has been overcome, and even in many places a sufficient supply has been assured to render it possible to think of irrigation.

The first section of the line, from the Caspian to the foot of the hills, is very deficient in water, but artesian wells have been sunk with good results, especially at Mulakbar station, where an enormous quantity of water has been obtained.

The second section, running along the foot-hills, is also deficient in water, but Professor Mushketoff is of opinion that under the upper clays will be found a water-bearing tertiary formation resting on compact blue clay. All along the slopes of the hills springs are met with, and the engineers engaged on the works have found water, not always sweet, however, several miles away.

The rainfall in the district being small, the true source of subterranean water must be in the distant hills, in which the rainfall is very considerable.

After skirting the hills for some distance the railway leaves them, and crosses the oasis of the rivers Tedjen and Murghab.

The River Tedjen, which is still very little known, carries a considerable quantity of water, as much as 14,000 cubic feet per second during the months of March, April, May and June; but in the autumn and winter it becomes quite dry, though it is believed that a large body of water flows underground through the porous strata forming the river-bed, and means are being considered of intercepting this flow and bringing it again to the surface. In any case the valley of the Tedjen abounds with water sufficient even for irrigation.

The River Murghab has been well explored. In spring and summer it carries about 10,000 cubic feet per second, and in winter 3,000 cubic feet. It is about 280 feet broad, and from 3 feet 6 inches to 7 feet deep. Ancient dams, constructed in the most primitive manner, exist for irrigating the Merv oasis. By improving these dams, and by constructing proper irrigation channels, it will be possible to bring more than 1½ million additional acres under cultivation. On this account plans have been made for a stone weir with movable crest, to be placed near old Merv, at an estimated cost of £12,000.

Upon the whole there is no reason to doubt but that it will be possible to find water enough to make the environs of the railway, thanks to the climate, so productive that it will change from a purely military line to an important highway of commerce. In the Merv oasis wheat and rice produce from seventy- to eighty-fold, and cotton thrives exceedingly.

The proposed extension of the line to the Amu-Daria will be under totally different circumstances; a desert of perfectly barren shifting sands will have to be crossed, storms, with hot winds rising to 147° Fahrenheit, will have to be encountered, and although it may be possible to obtain water enough for the needs of the railway, there is no use in even thinking of irrigation.

W. A.

The Trans-Caspian Military Railroad. By L. SCHTERBAKOFF.

(Ingener, St. Petersburg, 1886. From Students' Reports, p. 792.)

The construction of the Aschabad section of the Trans-Caspian Military Railway is not remarkable for any specially interesting engineering features; these notes, therefore, have reference chiefly to the methods of construction, and to descriptions of the work-people employed. The Author of the reports, having been in charge of various sections of the line, was in a peculiarly favourable position for describing all the minute details which are of so much importance with reference to estimates and plans for similar works.

The report commences with a general description of the line which skirts the Kopet-dag hills at a distance of about 2 miles. The earthworks are very insignificant, and the bridges confined to mere culverts; the rails, rolled at the Putiloff works, are about 62 lbs. to the yard, laid on wooden cross-sleepers.

The line is single. The ground is sandy clay, into which rain-water penetrates to a depth of 10 feet, so that, after the rare tropical storms, all communications are rendered impossible, men and horses alike sinking into the ground from 3 to 4 feet. This circumstance gave rise to great anxiety respecting the future of the line; for the embankments are made out of side-cuttings, and the foundations of the bridges are laid only about 4 feet 3 inches below the normal surface, which, in the Achal-Tekinsk oasis, is from 210 feet to 350 feet above the level of the Caspian Sea, yet in six places, on sinking wells, bitterly salt water was reached at from 84 feet to 112 feet below the surface. Only on the third section of the line, in two places, was fresh water found, and that at a height of more than 280 feet above the Caspian level. Throughout the depth of the excavation sea shells and water-worn gravel abounded, which, together with other indications, prove that the Caspian must, at one time, have extended to the foot of the Koept-dag hills.

The mean height of the embankments was 2 feet 3 inches, the maximum 7 feet 9 inches, and the deepest cutting was 1 foot 6 inches. The total quantity of earthwork in the first 23 miles was 199,377 cubic yards, executed at a cost of $4\frac{3}{4}d.$ per cubic yard. On the third and fourth sections 37 miles long, there were 344,068 cubic yards of earthwork, executed at the same rate.

The surveys showed that the railway ought to be carried near the hills, on account of the valley, which attains a horizontal cross-section about 5 miles from them, forming a bottom in which the water draining from the hills collects, and only disappears by slow soakage into the ground and by evaporation.

The fall of rain is not nearly so rare as Mr. Lessar reported it to be, so that considerable difficulties have been experienced in establishing the line on the slopes, on account of the irresistible torrents which occasionally sweep down from the mountains. The silty nature of the ground rendered it impossible to control these torrents, so that an immense number of culverts, of from 7 to 14 feet wide, had to be constructed, a bridge being placed at every spot where the water was likely to make its way. The construction of the Aschabad section of the line 137 miles long, forming the extension of the first section of the Trans-Caspian Railway, 143 miles long, was commenced at the end of May 1885. At first there were no Russian workmen; Persian labourers were attracted by the promise of "baksheesh;" the local tribes at first refused to work on any terms, though later on they became tolerable navvies. The first drafts of men were divided into squads of one-hundred and twenty-five; each squad had its ganger at £8 to £10 per month, an under-ganger at from £4 to £5 per month, and a storekeeper, who often acted as caterer and interpreter, at from £3 to £4 per month. The men declined to work at per cubic yard or per lineal yard, and at first nearly the whole of the earthwork was done by the day, the men receiving from £1 8*s.* to £1 12*s.* per month of twenty-six days. The quantity of work done was most unsatisfactory on account of the incorrigible laziness of the Persians. About 1·9 cubic yards of earth, carried from side-cutting, was all that could be accomplished, and no appliances of any kind except small wooden boxes carried on the shoulders would be used. It became evident that work could not go on in this way, some kind of piece-work must be established, and at last the plan of marking off a certain volume to be worked out by each man was, in the end, found successful, payment in full being made as soon as the work was finished instead of once a month, the result being that the men earned about 60 per cent. more money. At first, under the day-work system, the working hours were fixed, on account of the heat, from 4 A.M. to 7, from 7.30 to 10, and from 4 P.M. to 8.15; but when piece-work was established the men turned out at 2 A.M. and worked till 11.30, and again from 1 P.M. to 9, and even, on moonlight nights, they often worked all night. The men ate sparingly, their only food being "churek," a coarse kind of bread like a thick pancake, hard to

digest, and water they had very little of, and that little was often a day late in arriving. They slept occasionally in their tents, but more often simply in the newly-made slopes of the embankments. The quantity of work done by each man at last rose to 4 cubic yards, and he earned double as much money as he could do by day-work. The number of men in each gang continued to increase as the works advanced, and the difficulty of supplying water increased in proportion. There were very few horses; camels, costing £6 to £7 apiece, carried each about 37 gallons in two casks. Attempts were make to break the camels into harness, but failed, with few exceptions. The Persians, under all these difficulties, worked remarkably well; a whole gang could never be seen at once, a cloud of dust enveloped it, and only now and then the gleam of a spade or a tawny perspiring face could be made out. The engineers could only fix the levels and measure up the work during the dinner-hour, that is, in the extreme heat of the day. The masonry was all rubble, built of stones brought from the hills, laid in mortar composed of two parts sand, one part slacked lime and one-fourth part hydraulic cement. The stone cost about 23*d.* per cubic yard, so long as the line ran near the hills, but, on approaching Aschabad, where it turns away from them, the cost was nearly trebled on account of the length of transport. Excellent lime was burned on the spot; the fuel used was a kind of scrub called "saksaool;" the cost ranged from £2 to £1 per ton; the stones were often at 132° Fahrenheit when put into the kilns. The cement was brought from Moscow. Two gangs of stonemasons, numbering eighteen men each, were formed of Armenians, under Russian foremen; they received from £4 to £6 per month. Forty-six bridges were built under the Author's supervision, each bridge averaging about 76 cubic yards of masonry.

The laying of the permanent way was commenced in the beginning of July, in the presence of Generals Komaroff and Annenkoff, after a solemn religious service, by the 2nd and 4th Companies of the Second Trans-Caspian Railway Battalion, numbering two-hundred men. The rate of laying ranged from $1\frac{1}{3}$ to 2 miles per day. A train carrying the materials arrived in the morning and discharged its load on both sides of the line. The sleepers and rails were carried forward on trollies, the sleepers were then recessed to templates, for the rails which were laid down, bolted together, spiked, straightened, and set up with ballast, each operation being performed by special gangs. At noon a second train arrived, and was treated in the same manner. Later on considerable assistance was given by a light, portable railway, laid ahead by the side of the main line, along which the sleepers and rails were carried in advance. The third company of the railway corps was employed in laying the sidings at the stations in advance of the line, the materials for this purpose being brought up, from the end of the main line, by horse and camel traction. The importance of preparing the stations in advance was very manifest, the work requiring much more care and labour, absorbed the energy of five

hundred men. As soon as the line came up to a station the forty-five house wagons were moved up and a fresh depôt of materials was formed. No station-houses have yet been built. At the second-class station, Kodsh, a wooden house, 14 feet by 21 feet, has been erected, and a water-supply of about 12,000 gallons a day has been secured from a spring at the foot of the hills about 1¼ mile off. Temporary water-supplies were obtained from the water-courses crossing the line, the water being pumped by hand into tanks raised on piles of sleepers.

However successful the line may be in point of solidity and cheapness, much is still wanting. There is a total absence of fuel, and the Bay of Michailoff is so shallow that sea-going craft have to transfer their cargoes to shallow-draught vessels at Krasnovodsk, and the difficulties arising from this operation, and the want of vessels, frequently caused serious delays. Until the line has its own supply of naphtha, and is extended to the port of Krasnovodsk, it cannot be worked regularly and with advantage.

W. A.

The Importance of Ballast in Maintenance of Permanent Way.

By — Burkhardt.

(Organ für die Fortschritte des Eisenbahnwesen, 1886, p. 79.)

As a result of experience with iron sleepers increased attention has of late been given to the condition of the ballast.

Lengths of ballast of medium quality, in which wooden sleepers appeared to be dry, have proved unsatisfactory with iron sleepers. By means of their pumping-action the latter draw the wet up from below, and work the ballast up into mud, making a solid bed impossible. This working up into mud occurs also with wooden sleepers, but only after the ballast, having become completely impermeable for water, requires renewing.

The reasons for this difference may be stated as follows:

1. The iron sleeper has twice the deflection of the wooden one.

2. On account of the accurate fastening of the rail to the iron sleeper it shares the whole vertical motion of the rail, whereas with wooden sleepers the play of the foot of the rail in the dogs, and the compressibility of the timber, both tend to lessen the deflection of the sleeper.

3. The hollow body of the iron sleeper is very favourable to the formation of an air-tight cavity, inducing the pumping action above referred to.

4. The under surface of the wooden sleeper lies twice as deep as that of the iron one.

The working up of the ballast into mud by iron sleepers on certain trial lengths has interfered with their more general introduction, whereas the failure should have been put down to the

inferiority of the ballast and its impermeability to water. It would be found that in similar ballast there is wet at the bottom of wooden sleepers. These considerations lead to the question, Is enough attention given in Germany to the nature of ballast in the construction and maintenance of railways?

The free-lying ballast introduced by Stephenson on English railways is now the universal rule in Germany; the old German system ("Koffer-system"), or curved-surface system, being entirely superseded; but not only in the form, but also as to the material of the ballast the English chose right at first.

Very little broken stone is used for ballasting German railways, as is shown by the prices of ballast as taken from "Statistics of the Railways of Germany," and given in the following Table:—

Date.	Price per cubic yard.		
	Average.	Maximum.	Minimum.
	s. *d.*	*s.* *d.*	*s.* *d.*
1881–2	1 5	4 8	0 3
1882–3	1 5¼	4 7	0 2¾
1883–4	1 5	5 0	0 3

The bulk of the prices range between 9*d.* and 2*s.* 3½*d.* per cubic yard; this shows that there cannot be much broken stone used, the bulk of the ballast being land- and river-gravel, sand or cinders. The advantages of the use of broken stone ballast is not as yet appreciated in Germany, the ballast material being chosen on account of cheapness in first cost. The Author considers that broken stone is to be preferred to gravel in all cases. Good ballast must fulfil the two following conditions:—

1. It must be capable of being beaten up under the sleeper into a firm mass so as to afford the greatest possible resistance to the deflection when the load comes upon the sleeper, and also the greatest possible resistance to shaking loose.

2. At the same time the material must be such that between the sleepers there may be among it interstices for the passage of water, but also the greatest possible cohesion and friction to prevent slipping, and to distribute equally the pressure of the load.

Broken stone fulfils the conditions in a much higher degree than gravel. There is much more friction between the various angular fragments of the broken stone than between the round pebbles of gravel, and on this account the broken stone when once beaten up retains its place better than the gravel which constantly shakes loose. No doubt a firm bed for the sleeper is more easily obtained in the first instance with gravel as the small stones and sand fill up the interstices between the larger ones, but this is far out-

weighed by the great advantage of the superior drainage resulting from the use of broken stone.

It is usual in Germany for the ballast to be laid to not more than 10 inches below the underside of the sleepers. With gravel ballast this is too little, as owing to capillary attraction the water stands in the gravel, and also drains off very slowly. The depth should be 12 to 14 inches below the bottom of the sleeper, according to the nature of the formation. Usually no attention is paid to this, the thickness of ballast being uniform throughout, whereas the line stands much better when the formation is permeable than when it is not, however excellent the drainage may be.

The Author considers that instead of the ballast being renewed when the line is relaid as is now usually the case, the lower portion of it being then choked with fine matter and impermeable, it should be kept constantly clean by being from time to time opened out and screened, the fine matter being removed, and the coarse replaced, the deficiency being made up with new material. This method would be more in accordance than is the present practice with the principle that ought to guide permanent-way maintenance, namely, that every part of the permanent-way must always be kept in a condition answering to its function, the maintenance being prospective and continuous.

W. B. W.

Jointed Cross-Sleepers. By J. W. Post.

(Organ für die Fortschritte des Eisenbahnwesens, 1886, p. 60.)

Mr. C. Renson, Sectional Engineer on the Netherlands State Railways, has invented and had in use since 1882, a system of using up old wooden sleepers, thereby effecting a considerable saving in the cost of maintenance of permanent way. In looking at old sleepers of half-round or rectangular cross-section, it is seen that most of them have failed because of defects where the rail rests on the sleeper, while in most there is a length of from 3 feet to 3 feet 3 inches between the rails where the sleeper is pretty good. Mr. Renson joins together two such pieces, laid end to end, and inclined inwards so as to give to a rail laid across each the necessary 1 in 20 cant, by a length of inverted channel iron let into the timber, so that its web lies upon the upper surface, and bent at its half-length so as to keep the two half sleepers at their correct 1 in 20 inclination. The rail rests on the channel iron, which thus prevents it from wearing into the sleeper.

The sawing, dressing, boring, and putting together of these compound wood and iron sleepers can be done by the platelayers in wet weather, and the cost is therefore very small. The laying and beating up are the same as in the case of ordinary wood sleepers.

The two discarded ends of the old wood sleeper may be used up in various ways; the best of them being available for use in similar compound wood and iron sleepers for tramways and narrow-gauge lines.

As these compound sleepers have four end-faces, they offer more resistance to lateral motion than the ordinary wood sleeper.

In July 1882, Mr. Renson laid a quantity of these sleepers in a main line through a station: and in September of the same year a further number on a main-line curve of 50 chains radius, and a gradient of 1 in 62, over which thirty trains a day ran, some of them expresses. Both these lengths have required no different treatment from the adjoining lengths laid with ordinary wood sleepers, while the gauge has remained exactly true.

In the making of steel cross-sleepers there are always some waste-pieces, for which hitherto little use has been found. Many makers who cannot conveniently use them up, sell them very cheaply. In order to reduce the price of normal steel sleepers, and to provide a cheap steel sleeper for tertiary and secondary lines, it has been attempted to produce a cheap cross-sleeper out of these waste-pieces by riveting together two short pieces. This attempt may now be looked upon as entirely successful, and the practicability of it proved, and the cheap production of such sleepers is possible at all steel-works which have plenty of waste, and the necessary machinery for riveting the joints quickly, cheaply, and well.

The Netherlands State Railways Company, in June 1885, laid a number of such sleepers on a curve of 26 chains radius, on a gradient of 1 in 62. These sleepers have shown no disadvantages during loading, unloading, laying, or beating up, and required no more beating up than the ordinary steel or wood sleepers near them. As the riveting is at some distance from the rails, and consequently not much affected by the vibration, it is expected to stand well. There are six different types of these riveted sleepers, in all of which the rivets are 0·79 inch diameter. The joint may be 6 inches from the centre of the sleeper, so as to allow of short pieces being used up.

The Paper is accompanied by a number of drawings, giving details of the various methods of making the joints.

W. B. W.

Wear of Steel Rails in Germany. By — Coüard.

(Revue Générale des Chemins de fer, April 1886, p. 260.)

Mr. Coüard refers to his previous article on the wear of rails,[1] in which he drew the deduction that the wear of rails is relative rather to the number of trains than to the tonnage weight. In

[1] See Minutes of Proceedings Inst. C.E., vol. lxxix. p. 439.

the present article he shows that, on this basis of comparison, steel rails wear out faster in Germany than in France, and that the wear does not depend only on the chemical composition, but also on their section and on their substructure. The steel of the German rails may be milder, less resistant to flexure vertically, and supported on sleepers more widely apart.

Dealing first with ordinary rails laid on transverse wood sleepers, he gives a Table of the wear of rails in Germany; and he draws the general conclusion that a steel rail appears to wear more quickly in proportion as it is deflected by the passage of trains. Thus also he explains the fact, before noticed, of the greater wear of the outer rails of a double line of way, under which the packing of the sleepers is less perfect than under the inner rails next the "six-foot."

Here follows in the article a Table of the wear of steel rails on the Paris, Lyons, and Mediterranean Railway, deduced from measurements taken in March, 1885. There are rails of two sections, weighing respectively 78·6 lbs. and 68·5 lbs. per yard, laid on 2,150 and 1,881 sleepers per mile respectively. It is shown that the wear of such rails on these two sections as are produced at the same factory is sensibly the same; and it is concluded that, beyond the conditions of the lighter of the two rails, additions of strength do not sensibly augment the resistance of the rails to wear. Now, the wear of the 68·5-lbs. rails just noted varies between 215,000 and 128,000 trains per millimetre ($\frac{1}{25}$ inch) of height, or per 60 square millimetres of section (0·093 square inch), whilst the resistance to wear of the German rails, weighing 76 lbs. per yard, laid on 1,935 sleepers per mile, is only measured by the passage of from 151,700 to 82,700 trains, showing that the durability of the French rails is 50 per cent. greater than that of the German rails.

The difference of durability is explained by the chemical compositions of the two rails, which are here averaged as follows:—

Percentages.	Carbon.	Manganese.	Total.	Silicium.	Phosphorus.	Sulphur.	Copper.
German rails (five samples) .	0·31	0·33	0·64	0·08	0·09	0·02	0·14
French rails (four samples) .	0·83	0·69	1·52	0·15	0·05	0·05	..

The French rails have more than twice as much carbon and manganese in their composition, and wear longer than the German rails. This is a conclusion corroborative of that at which the Author had previously arrived. It applies only to rails on ways of low gradients and curves of large radius, clear of tunnels and stations.

German Ways entirely of Metal.—A comparative Table is given showing the respective durability of ordinary ways on transverse

wood sleepers, and ways on metal sleepers:—the Vautherin, the Hohenegger, longitudinal sleepers 32 feet long, with a transverse sleeper to each length; the Hilf, longitudinal sleepers 24½ feet and 29½ feet long, with a transverse sleeper to each length. The comparative results of wear show, (1), that with the Vautherin sleeper the wear is three times as much as with wood sleepers; (2) with the Hohenegger way the wear is four times as rapid as with wood sleepers; (3) with the Hilf way the wear of the rails is from four to five times as great as with wood sleepers.

D. K. C.

Steel Rails.

(Ingener, St. Petersburg, 1886, pp. 305 and 619.)

A Commission, consisting of representatives of the Ministry of Ways of Communication, of the Mine Corps of the Imperial Russian Technical Society, of various Railway Companies and Steel Works, held its first meeting on the 15th of January 1885.

The object of the Commission is to determine the tests to be applied to steel rails, the duration of guarantees to be given by the makers, to establish standard sections and lengths, and to define the chemical composition and physical properties of steel in tires and axles.

Mr. Annitchkoff laid before the Commission data collected by the Ministry of Ways of Communication, from which it would appear that the Russian rails are less durable than those made abroad, on account of milder material used in their manufacture, which was supposed to be necessary in order to meet the conditions of severe cold to which the rails are subjected in winter. Experience, however, has shown that the Russian rails do not enjoy greater immunity from fracture than others, and that consequently it would be desirable to amend the specifications so as to attain greater durability.

Mr. Verchofsky read a report prepared by a Committee of the Imperial Russian Technical Society, on the investigations made on steel rails taken up from roads under various conditions. The specimens were tested chemically and mechanically, and the results tabulated. The comparison of the data so obtained, revealed an apparent absence of general laws connecting the chemical with the mechanical properties of steel, yet the conclusion is arrived at that steel rails may be hard and yet not brittle, and that the best rails may possess a degree of hardness exceeding even that of rails which, on account of their brittleness, are unfit for service, and that the best rails contain more carbon and manganese than those which wear out quickly.

Professor Belelubsky presented a report on the work, similar to that which had been undertaken by the Commission, which was being done abroad, especially in Germany, and after some discussion it was agreed that the quality of rails as defined by the

existing specifications was unsatisfactory, and two Committees were appointed, one to draw up a new specification, and the other to work out standard sections and lengths of rails. Copies of the various reports alluded to had been circulated among those interested in the subject under consideration.

W. A.

Conical Tires of Railway Rolling-Stock a cause of Resistance to Traction, and of the Travelling of the Rails.

By — Krüger.

(Organ für die Fortschritte des Eisenbahnwesens, 1886, p. 132.)

The movement of a free cone (complete or truncated) lying on a plane, and having motion imparted to it, is always in revolutions round its apex. Any other motion requires the continuous application of outside forces, and is accompanied by definite resistance.

Let the cone whose axis is A S be forced to move, while rolling on a plane, in a direction at right angles to its axis. The axis will move parallel with itself. When the base has rolled one complete revolution without sliding, the axis will be in the position A_1 S_1, the length A A_1 being $2\,r\,\pi$ if r is the radius of the base of the cone.

The apex S will have slid upon the plane from S to S_1 [$S\,S_1 = 2\,r\,\pi$].

Let r_1 be the radius of the cross-section of the cone at a distance b from the apex, then if H is the height of the cone,

$$r_1 = \frac{b}{H} r.$$

When the cone has reached the position A_1 S_1 the cross-section at b will have rolled a distance of $2\,r_1\,\pi$, and slid a distance of $2\,\pi\,(r - r_1)$.

Join the points S A_1 by a straight line. A line parallel to A A_1 and distant b from the apex of the cone represents the path upon the plane of the section of the cone at distance b from the apex. This line is divided into two parts by the line S A_1, the portion lying in the plane A S A_1 [$= 2\,r_1\,\pi$] is the distance rolled, while the part lying in the plane S A_1 S_1 [$= 2\,\pi\,(r - r_1)$] is the distance slid. From the above it follows that a force (Z), causing a forward motion of a cone in a straight line, has to overcome a certain amount of friction due to the weight of the cone (G_1). If the cone is supposed to be weighted with a load G_3 uniformly distributed over its whole length, the friction will be proportionately increased. Let this load be represented by a cylinder of the same height and the same density (ρ) as the cone.

In that which follows only the truncated cone will be considered, as it only is of importance in practice.

The radius (a) of the load-cylinder is given by

$$G_3 = \rho\, a^2\, \pi\, h,$$

where h is the height of the truncated cone, whose base has a radius r and top radius r_1.

If μ is the coefficient of friction, the work done by the force Z in rolling the truncated cone in a direction at right angles to its axis is—

$$A = 2\,\pi^2\,\rho\,\mu\,\frac{H}{r}\int_{r_1}^{r}(a^2 + x^2)\,(r - x)\,d\,x,$$

or since

$$\frac{H}{r} = \frac{h}{r - r_1}$$

$$A = 2\,\pi^2\,\rho\,\mu\,\frac{h}{r - r_1}\left\{\int_{r_1}^{r} x^2\,(r - x)\,d\,x + a^2\int_{r_1}^{r}(r - x)\,d\,x\right\},$$

from which

$$A = \frac{\pi\, r}{2}\,\mu\,\rho\,\frac{h\,\pi}{3}\,\frac{r^3 - r_1^3}{r - r_1} - \frac{\pi\, r_1}{2}\,\mu\,\rho\, r_1^2\,\pi\, h + \pi\,\mu\,(r - r_1)\,\rho\, a^2\,\pi\, h.$$

In this, however, $\rho\,\frac{\pi\, h}{3}\,\frac{r^3 - r_1^3}{r - r_1}$ is the weight G_1 of the truncated cone, and further $\rho\, r_1^2\,\pi\, h$ is the weight G_2 of a cylinder of the height h of the truncated cone and radius r_1 (the radius of the top of the truncated cone) while $\rho\, a^2\,\pi\, h$ is the weight G_3 of the load cylinder.

Hence $$A = \frac{\pi\,\mu}{2}\left\{r\, G_1 - r_1\, G_2 + 2\,(r - r_1)\, G_3\right\};$$

but as $$\frac{G_1}{G_2} = \frac{\rho\,\frac{\pi\, h}{3}\,\frac{r^3 - r_1^3}{r - r_1}}{\rho\,\pi\, h\, r_1^2} = \frac{1}{3}\left(1 + \frac{r}{r_1} + \frac{r^2}{r_1^2}\right),$$

then

$$A = \frac{\pi\,\mu}{2}\left\{G_1\left(r - \frac{3\, r_1}{1 + \frac{r}{r_1} + \frac{r^2}{r_1^2}}\right) + 2\,(r - r_1)\, G_3\right\} \quad . \quad \text{(I.)}$$

If the velocity (the distance travelled by the cone in a second) be v, and if the base of the cone makes n revolutions in a second—

$$Z = \frac{A\cdot n}{v} = \frac{A}{2\, r\,\pi} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(II.)}$$

The Author proceeds to apply the above results to find the resistance to motion caused by the conical form of the tires of railway rolling-stock.

If two truncated cones are imagined connected at their bases, rolling along two intersecting inclined planes, the difference of

length of path $2\pi(r - r_1)$ rolled by the two ends of each cone in one revolution may be made up in two ways. If the small end of the cone rolls without slipping, the difference is made up by the larger end slipping with the rolling; while if the larger end rolls without slipping, the smaller end must be pushed along sliding. The different manner in which the difference is made up in these two cases seems to preclude the possibility of a third condition, under which the middle section of the frustum should roll without slipping.

The latter of the two modes of making up the difference $2\pi(r - r_1)$, requires, as shown above, a force Z working on the axis of the cone in the direction of its motion, which, in the case of railway rolling-stock, is provided by the draught of the engine. The former mode, however, would require the action of forces which could turn the cone on its axis, and whose point of application must therefore be without the axis. Forces of this nature are not in operation on the axles of moving railway carriages, with the exception of the force imparted to the axles by turning them. The action of this last upon an axle drawn by an outside force and rolling, can only come in when the friction caused by this movement on the edge of tho wheel is greater than the whole friction μG_3, no account being taken of the weight of the cone itself. The amount of this friction may, however, be obtained from equations (I.) and (II.)

$$Z = \mu G_3 \left(\frac{r - r_1}{2 r_1}\right)$$

which is only a small part of the total friction μG_3.

From the condition $Z \angle \mu G_3$, it follows that the two cones roll without their largest base sliding, and that the difference $2\pi(r - r_1)$ is made up by the smaller end of the cone being pushed forward sliding in the direction of motion. So the resistance to pulling forward offered by the conical form of wheel tires may be got from (II.), A being obtained from (I.). These two formulas hold good for any number of pairs of connected cones drawn forward, if the total weight of all the pairs be put for G. It must be noted that G_1 is the weight of the tires only; the weight of the axles and bodies of the wheels being included in G_3.

Some examples are worked out to show that from 6 to 20 per cent. of the total resistance is due in various cases to the coning of the wheel tires.

Cylindrical wheel-tires would do away with this loss of power, and consequently reduce the cost of haulage. Their use would also lessen considerably the wear and tear on tires and rails.

The slipping motion of the lesser end of the cone in the direction of motion of the train is probably the explanation of the creeping of the rails in the direction of the traffic. The great loads which are being continuously drawn with a sliding friction give the rails an impulse in the same direction.

W. B. W.

Improvements in Locomotives in France. By — Ricour.

(Compte-rendu de la Société des Ingénieurs-civils, 1885, p. 684.)

Mr. Ricour refers to a preceding article on the subject in the Compte-rendu for June 1884, and he now communicates the results of additional experience.

Piston-, or cylindrical valves, wear at the rate of 1 millimetre for 200,000 kilometres run ($\frac{1}{25}$ inch for 125,000 miles), whilst with the slide-valve the same extent of wear takes place after 2,060 miles are run, or about one-sixtieth of the mileage-run. The wear of the valve-gear is reduced in the same proportion. The effect of the change in reducing the consumption of fuel is proved by the returns made at the Saintes station, which show that in the year 1882, when all the engines worked with slide-valves, the coal consumed per 1000 tons conveyed 1 mile was 266 lbs., against 234 lbs. in the year 1884, when thirty out of forty locomotives had been fitted with cylindrical valves:—showing an economy of 12 per cent. in fuel.

The brick arch or partition, commonly erected in the fire-boxes of locomotives in England, has been introduced on the State railways of France. The bricks of which the partition is formed are supported on water-tubes, rising from the lower part of the tube-plate to the crown-plate, so disposed that the partition takes the form of the letter V, and tends, by its form, to direct the flame towards the sides of the fire-box.

The Author has made experiments on the resistance of the atmosphere to railway trains, by means of balances placed to the right and to the left of the cab or shelter on the foot-plate, having disks of 1 decimetre (about 4 inches) square, and a needle showing the resistance on a spring. The resistance varies as the square of the speed. At a speed of 44 miles per hour, the resistance is equal to 10 lbs. per square foot. The resisting-surface of a locomotive with its tender, in the direction of motion, is about 135 square feet, and the total resistance at the above rate would amount to ($135 \times 10 =$) 1,350 lbs. This resistance could be considerably reduced by the adoption of inclined surfaces, which have already been applied to some engines. Mr. Ricour estimates that an increase of 13 per cent. of useful work would be effected by their adoption; and he estimates that, if all the stock of the State railways were modified as he has indicated, the cost of traction would be reduced £160 per engine per year; and the total reduction for all the seven thousand locomotives now in France would amount to upwards of one million sterling.

D. K. C.

The most recently constructed Narrow-gauge Railways in Saxony.

By C. Köpcke and P. Pressler.

(Der Civilingenieur, 1886, p. 161.)

This is the last of a series of articles in which the Authors describe a group of recently constructed narrow-gauge railways. Abstracts of two of these have already appeared,[1] and this, the fourth, refers to the Radebeul and Radeberg line, which commences at Radebeul, at the south-east end of the station of that name, upon the main line from Leipzic to Dresden, and within a short distance of the latter city. It runs northward, through a district, either agricultural or forest, the soil being alluvial excepting in the highest lying ground, where granite is met with. The population in the immediate vicinity of the line is about 9,300, including the town of Radeberg (2,750), and the picturesque character of the country traversed serves to attract additional passenger traffic.

The gauge of the railway is 2 feet 5½ inches and its length 10·34 miles, of which 7·94 miles, or 77 per cent., is straight, and 2·4 miles, or 23 per cent., is in curves, of which 0·4 mile (639 metres), or 3·3 per cent., is of the minimum radius, viz., 246 feet.

As regards gradients 4·64 miles, or 45 per cent., is on the level, and 5·7 miles, or 55 per cent., on inclines, the steepest being 1 in 60.

A longitudinal section gives the levels and the positions of the eight stations; these are from 1 mile to 1·85 mile apart. The level of the line (above sea) at the commencement is 370 feet, at the summit near Dippelsdorf 607 feet, and at the terminus Radeberg, 485 feet. Plans of the station yards at these places, and also sketches of the buildings, are given, together with their cost.

At Radebeul the arrangements for transferring goods from the narrow to the normal gauge wagons are of a simple character. The trans-shipment is effected either by a transfer platform, situated between a normal- and a narrow-gauge track, with its surface inclined transversely, and its edges of a height suitable to the rolling-stock of each gauge; or the narrow-gauge line is raised above the normal-gauge track sufficiently to bring the wagon floors of each to the same level. Narrow-gauge wagons or engines may be run into normal-gauge trucks, by an arrangement similar to an ordinary carriage-dock.

Sketches of occupation bridges and cross-sections of the line are given, also Tables of Bridges; culverts and retaining-walls, with their dimensions and cost; also the deflection of the girders

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 428.

under the test-load of one or more three-axled locomotives of 5 feet 11 inches wheel-base, and a weight of 5 tons per axle.

The rolling-stock comprises three locomotives, twenty passenger carriages, seven covered goods wagons, thirty open wagons, four cattle trucks, two pairs of timber trucks, &c.

The cost of the railway was as follows:—

	£	s.	d.	Marks.
Land	3,102	7	6	62,047 54
Earthwork, including rock and retaining walls	6,418	8	2	128,368 17
Fencing, exclusive of that at stations	21	18	9	438 74
Level crossings and road bridges	1,849	7	5	36,987 39
Bridges and culverts	2,770	17	9	55,417 73
Permanent way	13,540	14	2	270,814 13
Signals and cabins	256	3	1	5,123 08
Stations and platforms, &c.	5,447	6	8	108,946 68
Rolling-stock	7,140	2	7	142,802 64
Superintendence	4,927	9	10	98,549 82
Sundries	107	12	10	2,152 80
Interest during construction	546	18	5	10,938 44
Total	46,129	7	2	922,587 16

This gives a cost of £4,459 14*s.* per mile (55,400 marks per kilometre).

The works were commenced in September 1883, and the line opened the following September.

D. G.

On the Wire Ropeways between Vajda-Hunyad and Vadudobri (Transylvania). By — Bochart and — Lebreton.

(Annales des Mines, vol. ix., 1885, p. 185.)

The transport of material from Vadudobri, whence is obtained the charcoal used in the furnaces, and Gyalar, the centre of the ironstone mines, to the Hungarian State ironworks at Vajda-Hunyad, presents some special difficulties. The construction of even a narrow-gauge railway would have involved enormous expense, owing to the difficult nature of the country to be traversed, while the only road, and that a very bad one, has to make a detour of 30 kilometres (18½ miles), to accomplish a distance of 10 kilometres (6¼ miles) as the crow flies. It was, therefore, necessary to adopt a special system of cable-transport, which, in consequence of the difficult nature of the problem, presents several points of peculiar interest.

As a simple system on the Hodgson plan, in which a single travelling-rope serves both to carry and to transport the loads, was out of the question, owing to the gradients, which average about 1 in 30, and in special places are as severe as 1 in 7 or 1 in 8, it was necessary to adopt a pair of parallel carrying-cables for the

up and down lines, each served by a hauling-rope placed at a lower level, but in the same vertical plane.

The local variations in the gradients and in the quantities of material to be transported, the enormous strain on the hauling-rope that would have been required to work the whole distance of nearly 31 kilometres (19 miles) in a single length, and the impossibility of maintaining such a length of carrying-cables sufficiently rigid, necessitated a subdivision into sections as shown in the annexed Table; the length of each section, and the height of each station above Vajda-Hunyad being given in metres. From Vadudobri to Gruniuli, the line ascends; but from Gruniuli to Vajda-Hunyad, the descent is continuous.

Section.	Height in metres above Vajda-Hunyad.	Names of Stations.	Length of Section in Metres.	Average Gradient.
1	797	Vadudobri to *Gruniuli* . .	2,404	1 in 25
2	892	*Gruniuli* „ Plaiuli . . .	4,418	1 „ 45
3	793	Plaiuli „ *Bunila* . . .	4,277	1 „ 53
4	713	*Bunila* „ Pojinitza. . .	4,291	1 „ 64
5	646	Pojinitza „ *Ruda* . . .	1,882	1 „ 67
6	618	*Ruda* „ Gyalar . . .	3,603	1 „ 18
7	416	Gyalar „ *Catsenas* . . .	5,347	1 „ 24
8	192	*Catsenas* „ Vajda-Hunyad .	4,320	1 „ 23
		Total . .	30,542	

The motive-power stations are distinguished by italics, the others being merely shunting or transfer-stations. Each hauling-engine works two sections of road, except at Catsenas, where it was found preferable to have two engines and two boilers. The total motive-power at the four stations is 35 HP. Between Vadudobri and Gyalar only charcoal, and in some cases water for the boilers, has to be transported; but both charcoal and ironstone are carried between Gyalar and Vajda-Hunyad. It will be noticed that the most important stations—Vadudobri, Gyalar, and Vajda-Hunyad—are not encumbered with engines or hauling-machinery.

On section 7 there is a single span of 470 metres (514 yards), with a gradient of 1 in 6½; on section 8, a single span of 420 metres (356 yards), with a gradient of 1 in 11½; and on section 5, two single spans of 205 metres (224 yards), and 333 metres (364 yards) respectively. In such cases three, and even four, supporting-frames for the cables are placed close together side by side; but elsewhere, where the spans are much shorter, they are placed singly. These supporting frames consist of two upright posts of oak or hornbeam, which are cheaply procured on the spot, united by two cross-beams, from the upper one of which is suspended a frame provided with two small pulleys, on which the carrying-cables rest, while the lower one carries two rollers for the hauling-ropes. The height, and the size of the timbers, vary con-

siderably according to circumstances; but they may easily be carried up to, say 23 feet, two or more raking struts being added where necessary.

The carrying-cables—of steel, 1 inch diameter—are heavily loaded at each end with weights proportionate to the lengths, gradients, spans, and loads to be carried, which, as has been seen, vary considerably in different sections, and are supported on small rollers so as to be free to move under the influences of expansion, contraction, and deflection under varying loads.

The hauling is effected by a single endless steel rope (of $\frac{3}{4}$-inch diameter) for each section, serving both up and down lines. At the driving end it passes round a horizontal grooved pulley, 2 metres (6 feet $6\frac{3}{4}$ inches) diameter (corresponding to the distance apart of the ropes) driven by the engine, and at the other end round a pulley of similar size mounted on a sliding-frame weighted with a heavy counterpoise for keeping the rope taut. On it, at regular distances of 134 metres (147 yards) on the sections between Vadudobri and Gyalar, and of 54 metres (59 yards) on the sections between Gyalar and Vajda-Hunyad, where the traffic is the heaviest, are fixed small steel clips, which are gripped by an ingenious apparatus attached to each tub, an automatic releasing arrangement being provided at the end of each section of line, where the tubs are guided off the carrying-cables on to fixed rails of peculiar construction, until they are transferred to the next section and gripped on to the hauling-rope by the man in charge at each station. Wooden carrying-rollers are provided for the hauling-ropes when not in use, or when they sag to any considerable extent; but when in action they are supported by the tubs themselves.

The tubs, which are carried on trunnions so as to be easily tipped, are of bucket form, suspended from two grooved wheels travelling on the carrying cables by a frame which also carries the gripping apparatus above referred to. An empty tub weighs about 4 cwt., and will contain about 6 cwt. of ironstone, or about 2 cwt. (say 14 bushels) of charcoal. There are, at one time, 240 tubs of ironstone, and 434 tubs of charcoal (including returning empties) in circulation, travelling at about $2\frac{3}{4}$ miles per hour, and capable of delivering about 160 tons of ironstone, and 4,400 bushels of charcoal per day of ten hours.

It is not easy to estimate the cost of transport with any great accuracy, as the system has only been in operation for a very short period, and the data obtainable are incomplete; but it probably averages about 0·89 and 0·92 franc per ton per kilometre (1*s.* $1\frac{3}{4}$*d.* and 1*s.* $2\frac{1}{4}$*d.* per ton per mile) for ironstone and charcoal respectively, due allowance being made for depreciation and interest on capital. This is about one-half the cost of transport in bullock carts.

The Paper is illustrated by engravings showing sections of the line, and details of the carrying-frames, tubs, gripping apparatus, and hauling- and shunting-stations.

W. S. H.

On the Construction of the Locks in the Canals of Finland, and their Maintenance during the Winter.

By M. LEVANDOVSKY.

(Ingener, St. Petersburg, 1886, p. 232.)

The Paper commences by a brief description of the two principal canals in the south-eastern parts of Finland. The canal of the Saima connects a chain of lakes with the gulf of Finland, by a waterway 37 miles long, with a fall of 260 feet. The fifteen locks are all of substantial masonry, and are fitted with wooden gates, the use of iron, in connection with the stonework, being dispensed with as much as possible, on account of its considerable changes of volume, due to the great range of temperature to which it is exposed. The masonry, though built in hydraulic cement, suffered considerably from the severe cold of winter; but in the year 1870, the plan was adopted of covering the lock chambers by means of 2-inch planks, and allowing the water to flow perpetually through the two gate sluices. Snow is allowed to accumulate over the temporary covers, and as the water running through has a mean temperature of 39° Fahrenheit, the lock chambers are readily kept at a temperature a little above the freezing-point. The levels between the locks are kept full all winter; the Author points out that the practice of running out the water is destructive to the banks.

The canal of the Pielis, connects two lakes; it is 40 miles long, and has a fall of 62 feet, surmounted by ten wooden locks, the structure of which is described, the Author pointing out the advantages derived from making the lock chambers entirely self-contained and independent of the ground they are sunk in. The cribwork of the walls is loaded with stone, and not clay or earth, as is commonly the case, in consequence of which the woodwork is not forced out of place by the expansion of the frozen filling, and does not rot so quickly. The Paper is illustrated by a map and four sheets of plates.

W. A.

Extension, etc., of that portion of the Rhine-Marne Canal lying in French Territory. By M. VOLKMANN.

(Zeitschrift des Architekten und Ingenieur Vereins zu Hannover, 1886, p. 337.)

During the past ten years extensive works have been carried out in connection with this system of canals, which is one of the most important in France, these works include the construction of the Eastern Canal. The raising the water-level of the whole system, and the provision of an increased supply of water, neces-

sitated by this increase in depth, and a desire that the sources of supply should be situated within French territory.

A map and longitudinal section of the system, including the new Eastern Canal, and various diagrams, accompany the Paper. The original canal was constructed between the years 1838 and 1853, and commences by a junction with the Upper Marne Canal at Vitry-le-François, and terminates by a junction with the river Ill and the Rhine Canal, near Strasburg, thus connecting the valleys of the Seine and the Rhine, and also the intervening rivers, which include the Maas, Moselle, Saar, &c. Its length, between Vitry and Strasburg, is 193½ miles, and it crosses the four watersheds dividing the catchment basins of the Marne, Maas, Moselle, Saar, and Rhine; there are, however, only two summit reaches, as the divides between the Maas and Moselle, and the Saar and Rhine, are tunnelled through at Foug and Arzweiler respectively. There are altogether five tunnels, with a total length of 5½ miles.

The level of the water above the sea is, at Vitry, 332·62 feet at the Mauvages summit tunnel, through the Marne-Maas divide, 922·75 feet; at Nancy, 648·10 feet; at the Vosges summit level, 873·93 feet; and at Strasburg, 444·18 feet.

A Table of the various chains of locks is given, together with the levels; their number is one hundred and seventy-seven, and the mean rise of each 8·60 feet.

Some years since it was contemplated to increase the water-supply, but the improvements were delayed by the Franco-German war, which resulted in a transfer to Germany of the Alsatian portion of the canal, and also of one of the most important sources of supply, viz., the river Saar. To render the system independent of this latter portion, in 1874 the construction of the East Canal was authorized. This commences at Givet, on the Belgian frontier, joins the Rhine-Marne Canal at Troussey, and again leaving the latter canal at Toul, follows the course of the Upper Moselle to Epinal, where it branches off in a south-westerly direction to its termination at Port-sur-Saône. The depth of water in this canal was fixed at 6 feet 6 inches.

The Rhine Marne Canal had originally a depth of 5 feet 3 inches, a breadth at bottom of 32 feet 10 inches, and sides sloped at 1½ to 1. This depth has been increased to 6 feet 6 inches, the canal bed cleaned and lined with concrete, 6½ inches to 8½ inches thick where necessary, and the headway of bridges and tunnels raised to 12 feet 2 inches above the new water-level. Through the Mauvages Tunnel a chain has been laid, and all the traffic is worked by two chain steam-tugs with fireless boilers (Francq's patent).

The most important of the new works are those for the additional supply of water. They comprise pumping-stations at Pierre-la-Treiche and Valcourt, near Toul, at both of which the pumps are actuated by turbines, and a steam-pumping station at Vacon, also ducts for conveying the water from the pumping-stations to the canal, and an impounding reservoir at Paroy.

	Gallons.	Cubic metres.
The total amount of water required annually for the Rhine Marne Canal is	1,364,620,000	(6,200,000)
The total amount of water required annually for the East Canal	748,340,000	(3,400,000)
	2,112,960,000	(9,600,000)
In addition to which there is the Meurthe branch requiring	462,210,000	(2,100,000)
	2,575,170,000	(11,700,000)

Besides the above artificial sources, the canals are fed by springs at Vacon, and by the Moselle, &c.

The arrangements at Pierre-la-Treiche and at Valcourt are nearly similar. There are two turbines actuating force-pumps, capable of raising from 143 to 198 gallons per second to a height of 131 feet 3 inches, through a line of cast-iron pipes of 2 feet 7½ inches diameter, delivering into an open duct connecting with the east end of the Pagny Reach of the canal. This duct commences at Pierre-la-Treiche, and is 8¼ miles long, and feeds both canals.

	£.	Marks.
The cost of these works was	51,920	(1,038,400)
Of which the pumping station at Pierre-la-Treiche cost	15,616	(312,320)
„ „ „ Valcourt . . . „	26,908	(538,160)

The steam pumping-station at Vacon is near the west end of the Pagny Reach. The pumps are 250 HP., and capable of lifting 8,804,000 gallons per twenty-four hours to a height of 121 feet 4 inches, or 110 gallons per second. The water is conveyed into a duct, which also conducts the water from the Vacon springs, and empties into the Pagny Reach.

The reservoir at Paroy has an area of 180 acres, and contains 376,371,000 gallons. The dam is 1,378 feet long, and 18 feet 3 inches high; the cost of construction was £20,800.

Descriptions are given of two other reservoirs which are yet to be constructed, and also details of the canal traffic, which in 1884 amounted to 634,936 tons.

D. G.

Navigation by Night on the Suez Canal. By — Foris.

(Le Génie Civil, vol. ix., 1886, p. 161, 15 woodcuts.)

During the commercial depression of 1882–85, the traffic on the Suez Canal continued to increase so steadily that the Company had to consider how they could provide for the augmentation of traffic on the revival of trade. Besides contemplating the enlargement of the canal,[1] they have endeavoured to shorten the time of transit, so as to meet present requirements, by establishing navi-

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 473.

gation by night. Experiments were conducted for two years; and by fitting up electric lamps on a tug and some barges, projecting a beam of light, the conditions necessary for safe transit were ascertained. Accordingly, at the close of 1885, vessels of war and those carrying mails were permitted to pass by night between Port Said, and the fifty-fourth kilometre (29 nautical miles), provided they exhibited an electric beam in front with a range of 1,300 yards, an electric lamp astern capable of illuminating a circular area of from 220 to 330 yards in diameter, and an electric lamp with reflector on each side. During April, 1886, several vessels passed by night from Port Said to Ismailia, and traversed from sea to sea in sixteen to eighteen hours, thus saving from eighteen to twenty hours on the average time of transit. Special pilots are provided by the Company to steer the vessels through the canal, in which they are aided by buoys on each side, and by an even number of buoys of two different colours at the entrance to a channel; but care is needed to keep a vessel, over 330 feet long, of 26 feet draught, and 39 to 43 feet wide, in the centre of the canal, having a bottom width of 72 feet, and a depth of 28½ to 29½ feet. Light-giving buoys have been placed at the entrances to channels, lighted with compressed gas on Pintsch's system, and showing a green light to starboard and a red light to port. A white light, hung from a high post opposite each passing place, indicates the direction on the straight portion of the canal at every 5 or 6 knots; and as it is clearly visible up and down the canal to a distance of 7 or 8 knots, a vessel comes within sight of the following light when about a knot off the nearest one. A set of three red lights is hung from a projecting arm at the top of the iron trellis post, and, by the number exhibited and their position, afford the means of signalling to passing vessels. These lights are 33 to 36 feet above the water-level of the canal. The beam of electric light projected from the bows of the vessel, with its range of 1,300 yards, lights up the banks and about three to four pairs of buoys or beacons, and shows whether the path is clear in front. In the straight reaches, lights can be instantly exhibited at each side of the vessel, and astern, to show the pilot the exact position of the stern of the vessel in relation to the banks or a vessel being passed, by lighting up the buoys on each side and the banks behind. Along the curves, no lights are exhibited on shore; but the projecting beam indicates the banks and buoys in front, and the side and stern lights, which are then kept alight, show the banks and buoys alongside and behind. The Peninsular and Oriental Company have been furnished, by Messrs. Sautter, Lemonnier & Co., with movable apparatus, which is taken on board on entering the canal and landed at the other end. The electricity is generated by a Gramme dynamo with compound coils, worked by a Brotherhood motor, and capable of producing a current exceeding 75 amperes at a tension of 70 volts, 45 amperes being devoted to the light at the bows, 8 for each side-light, and 14 for the stern-light. The pilot is in telephonic communication with the man who regulates

the projecting beam of light, and, by commutators within his reach, can extinguish or light the side and stern lamps. The front lamp has a flat Mangin mirror, 1⅓ foot in diameter, and is fitted in front with plano-cylindrical lenses, affording a suitable divergence of rays, and it is placed on a movable plank at a height of 10 feet above the water-level, on which also the man stands who adjusts the carbon points and changes the direction of the beam of light as directed by the pilot. The first night trip was accomplished by the P. and O. steamer "Carthage," from Port Said to Ismailia, in nine and a quarter hours; and including two hours of stoppages, the whole passage through the canal was effected in eighteen hours, giving an average speed of 5·43 knots per hour. The success which has attended the navigation by night between Port Said and Ismailia ensures its easy extension to the passage of the large Bitter Lakes; and it is probable that, with suitable tides, Suez could be reached. Though this progress does not double the accommodation of the canal, yet it enables the mail-packets and vessels of war, constituting 22 per cent. of the whole number of vessels using the canal, to pass through the canal in a single day.

L. V. H.

Theories of the Tides. By A. de Préaudeau.

(Annales des Ponts et Chaussées, 6th series, vol. xi., 1886, p. 262.)

Newton, in his theory of the tides, adopted the inexact hypothesis that the waters of the globe assumed, at each instant, the position of equilibrium due to the forces acting on them; whilst Laplace considered that the moving water, owing to its acquired velocity, passed the position of equilibrium, and made oscillations whose period was proportional to the disturbing forces. Laplace, however, like Newton, based his calculations on the assumption of a globe entirely covered with water, which therefore do not manifest the working of the phenomenon. Assuming therefore a spherical globe, with the vertical passing through its centre in the ordinary conditions of equilibrium, and neglecting the density of the water as compared with that of the earth, then the infinitesimal divergences of the vertical under the attraction of the heavenly bodies, which are the primary causes of the tides, will depend solely on these attractions. According to Mr. Keller, the tidal currents are the result of transmitted differences of pressure, caused in the first instance by variations in the force of gravity due to the influence of the moon on the particles of water, owing to the difference between their distance from the moon and that of the centre of the earth. Mr. Hatt, on the contrary, in his work "Notions sur le Phénomène des Marées," of which this article is mainly a summary, considers that the tide is due essentially to a change in the direction of the vertical, and not to the inappreciable alteration of the force of gravity. The attraction of the moon

averages one twelve-millionth that of gravity, and that of the sun is a half less; whereas, when the declination of the moon is zero, it can deviate the vertical near the equator about a third. The first theory is very suitable for affording an elementary idea of the phenomenon; whilst the second conceives the tide as the result of currents produced by the deviation from the vertical under the attraction of the heavenly bodies, and the variations in height as the consequence of the conflict of the currents and of their changes. The movements must evidently be oscillatory, and the vertical displacements generally very feeble compared to the horizontal ones; and the semi-diurnal forces produce motions of the same period along the equatorial zone, but, owing to the inequality of the solar and lunar periods, the lunar tide is stronger than the relative attractions of the two bodies would indicate. The oscillatory motion is considerably modified in limited seas, so that the relation and relative situations of the solar and lunar waves may be greatly changed, which explains in principle the retardation, or age, of the tide observed on the western coasts of Europe. A general formula for the tides on these coasts is—

$$y = b_0 + b_1 \cos(x - a_1) + b_2 \cos(2x - a_2) + b_4 \cos(4x - a_4) + b_6 \cos(6x - a_6)$$

where y is the rise of tide, x the horary angle of the imaginary heavenly body producing the tide, and b_0 b_1 b_2, a_1, a_2, coefficients to be determined by observation, the number of terms being larger in proportion as the port is further inland. Local observations only indicate the results of the attractions of the heavenly bodies and of the littoral disturbances; so that it is important to study the influences of the former in order to appreciate properly the effects of the latter.

L. V. H.

The Tides of the Charente. By E. Decante.

(Revue Maritime et Coloniale, vol. lxxxix., 1886, p. 132, 4 woodcuts.)

Fears have been entertained that the deepening of the river Charente, undertaken between Rochefort and the sea, might modify the beneficial tidal regimen which has hitherto been so constant. From tide-gauge observations, extending over three years, before the works were commenced at the end of 1883, it appears that the mean heights of high and low-water were, 19·39 and 6·86 feet at Rochefort, and 18·67 and 5·77 feet at Fort Bayard in the roadstead outside the mouth of the river, giving average ranges of tide of 12·53 feet and 12·90 feet respectively. Though the limited duration of the tidal observations has prevented the establishment of the port (reckoned at 4 hours 8 minutes for Rochefort and 3 hours 51 minutes in the roadstead), and the unit of height of tide (calculated at 8·99 feet for both places), from being determined with precision, yet the minima heights of low-

water at Rochefort early in 1882, falling on several occasions to between 4·53 and 4·92 feet, prove that the idea that the tide had been lowered by the improvement works towards the close of 1884 was unfounded. The principal impediments to navigation, which are being removed between Rochefort and the sea, are the shallows of Avant-Garde, the rock of Gombeau, near Soubise, and the shoal of Fougueux, at distances of about $\frac{3}{4}$, $4\frac{1}{4}$, and $5\frac{1}{2}$ miles respectively from the arsenal, and with depths of $7\frac{1}{2}$, 5, and $2\frac{3}{4}$ feet below the zero of the marine charts. These shoals are being lowered to depths of $12\frac{1}{2}$ and $11\frac{1}{2}$ feet below the same level by the removal of 146,142 cubic yards of rock and 187,021 cubic yards of silt, an insignificant quantity compared with the bed of the Charente, and which might be augmented without producing any lowering of the low-water, since shoals lower down maintain the same opening at the mouth. Moreover the mean and minima levels of low-water in December 1884, were higher than those of February 1882, though the discharge of the river at the latter time was somewhat greater than at the former, whilst no other atmospheric influences can account for the difference. Under normal conditions, low-water at Rochefort takes place on the average 1 hour 34 minutes after the turn of the tide in the roadstead of Aix Island, at which time the water-level is higher outside than at Rochefort. As the attraction of the sun and moon determine the volume of water coming up, there could be no objection to the increase of the depth at the mouth at the expense of the width, provided the section and discharge remain the same. Nevertheless the lowering of the shoals of Lupin and Fouras, lower down the river, would be both a more thorough and a cheaper expedient. At neap-tides, the low-water level at Rochefort is below that of the roadstead, whereas when the tides improve the two become equal, and at spring-tides the level at Rochefort is always the highest. As, therefore, the introduction of a larger volume of water into the river raises the level of low-water at Rochefort, owing to the greater quantity of water, some of which is carried up further, being unable to get away before the turn of the tide, it follows that by facilitating the access of the tide up the river by the removal of shoals near its mouth, the low-water level at Rochefort would be raised, instead of being lowered as was supposed.

L. V. H.

Harbour Studies. By L. M. Haupt.

(Proceedings of the Engineers' Club, Philadelphia, 1886, p. 285.)

Parts 1 and 2.

Need of Deeper Water.—3,000 miles of deeply-indented Atlantic coast-line from New York to Mexico "would appear to furnish frequent retreats for shelter." The inlet "bottoms," however, generally reveal submerged obstructions; millions of money re-

quired to give entrance to a roadstead "even at a few distant points." A list of the harbours along this coast shows a general depth of 10 to 12 feet at low water over the bars, and reaching higher in a few exceptional cases, viz., New York, 23 feet; Norfolk, 21 feet; Port Royal, 21 feet; Tyber Roads, 20 feet.

As the largest ocean vessels draw from 26 to 28½ feet even at high water at New York, with a rise of 4·8 feet, "there would be danger of striking bottom even in still water." The greatest depth over crest of bar, accompanied by the greatest distance from the shore, show quantities varying with volume, direction and velocity of discharge. The tidal receptacles parallel to the shore "may be appropriately styled the twyers of the inlet, or the lungs of the ocean."

The Author advocates shaded zones for submarine topography instead of the present intricate system of dotted lines; also with justice equal scales for maps of the same locality, and equal time intervals of survey, say, every five or ten years, and the scales 400 feet to 1 inch = $\frac{1}{4,800}$.

After examining the physical laws as a guide to the general solution of the question, he states that in tidal waters submerged jetties permit the dissipation of the most vital parts of the force they are intended to conserve.

That there is on the part of the land forces a tendency to scour out in channels, and of the naval forces to build a bar. That efforts should be allied to first and opposed to last. He compares the action of wind and wave on a sandy bottom to the western prairie snow-storms, when it is invariably found that the windward slopes are swept clean, while to the leeward of obstruction, even though they be merely fences, the snow curls over and is banked up in drifts many feet deep. The ocean forces are recognised by him as—

1. The Gulf Stream, flowing from the Florida Keys, where it has a velocity of 3 to 5 miles per hour, diminishing to about 1 mile off Hatteras as the stream expands. The walls of this stream are well defined, and its force is very variable both in direction and intensity. Its bed is beyond the 100-foot contour.

2. A cold arctic shore-current in an opposite direction, forming along the river-wall numerous eddies, and along the coast complicated currents.

3. These streams both modified by tidal wave of diurnal variations of ebb and flow.

4. The opposition to the fresh-water discharge impounded by the ocean in lagoons, bays, sounds and estuaries, resulting in deposit before reaching deep water.

5. Force of winds and waves, which he estimates for first at 50 lbs. per foot, and of last at 2 to 3 tons.

He refers to effects of wind in movement of sand dunes 100 feet high on Carritade beach, the direction always indicated by the steepest side under the lee of the dune. Galveston and Charleston are quoted to illustrate the problematical results attendant on

low-water training-jetties. At the first, after eleven years' labour and two million of dollars expenditure, and 4¼ miles of submerged jetties, about 1 foot has been gained, the depth being increased from 12 to 13 feet at low water. At Charleston the result is still more negative, as ½ foot of water has been lost to navigation. These so-called "improvements" were commenced in 1878 at an estimated expenditure of from two to three million dollars. From a report in 1884 the sand is invariably more piled up on the sea sides than on the inner sides of the jetties, and the effect of the flood in piling up sand is greater than the ebb in the immediate vicinity of the jetties.

"Yet it is proposed to build a half-tide dyke 5 miles long at the entrance to the lower bay of New York harbour, and so create a general disturbance of all the channels which are considered permanent and improving. This is a case where a local concentration of forces upon some one outlet would be, in our opinion, a far more successful treatment." In conclusion, the Author quotes the case of Cromarty Firth, where at 50 feet depth the flood-velocities appeared to be more than doubled, and on the ebb nearly as at surface, as showing the danger of trusting implicitly to surface velocities.

A dyke rising to half-tide would, it is suggested, merely result in removal of crest of bar to seaward, without necessarily producing a better channel, and if only built to low-water level the source of great dangers.

Not daunted by the previous collapse of all such attempts by Captain Taylor, Colonel Parlby, W. H. Smith and others in this country during the last half century, a system of anchored, vertical, flexible deflectors is suggested as superior to submerged jetties.

Trautwine is quoted as regards amount of scour produced by contraction caused by piers, who observes that anterior to erection of obstruction the velocity is greatest at surface, diminishing gradually to bottom, but when a pier, &c., is built, the surface velocity actually becomes least, and is nearly uniform throughout entire depth, causing a much greater wearing-action at bottom than is generally supposed, and rarely adverted to by authors. The conclusion that the removal of shingle and sand from the bar will require the development of a bottom velocity of about 3 miles per hour, and that the concentration of the ebb stream by the suggested deflectors can be done to any desired extent.

Finally, these floating deflectors are proposed for the Mississippi as likely to produce what is above all wanted, viz., a uniform velocity. Of this river it is said, "In many places the jetties, wing-dams, dykes, revetments, &c., have worked very satisfactorily, and in others they have been of no avail."

"The proposed deflectors, it is believed, will accomplish this result (a relatively permanent condition) more effectively and cheaply than any other known device, thus converting what may be styled a horizontal or lateral treatment into a vertical one, and

thereby securing the full effect of gravity and momentum in regulating the discharge, by creating and maintaining a more nearly uniform velocity."

Part III.—Delaware Breakwater Harbour.[1]

Three hundred miles of the New Jersey shore is much exposed, and suffering much from recent storms, and the only available harbour along this dangerous stretch of shore is that at the mouth of the Delaware river. The breakwater was projected prior to 1828, and its construction authorized in May of that year, when the demands were insignificant compared with requirements of to-day, and its capacity then greater than now, due to subsequent shoaling.

The breakwater was based on the Cherbourg and Plymouth experiences, and sections will be found in our Parliamentary Blue Books on "Harbours of Refuge," a voluminous literature of its own. First load of stone delivered 18th April, 1829. Length, 2,558 feet on top, "extending in a straight line, which, if produced, would have been a tangent to the shore of the Cape at the time the work was projected. The distance, therefore, was about 4,200 feet. There is also an ice-breaker 1,359 feet long, making an angle of 146° 15′ with the line of the breakwater, which would intersect it near the middle if prolonged. Between the eastern end of ice-breaker and western end of the breakwater, there was left a gap of nearly a quarter of a mile."

Cross-sections.—The same—viz., 22 feet on top, 160 feet at base, and 14 feet above mean low-water.

Rifraf of stones varying from ½ to 7 tons in weight was deposited between 1829 and 1839; 835,000 tons = 400,000 cubic yards in place, at a cost of $1,800,000; but the real completion extended to 1869, when the expenditure amounted to $2,123,000.

Effect on Harbour.—In 1828 the 24-feet curve was ½ mile southwest, and nearly parallel to breakwater, giving "ample and good anchorage."

In 1879–1881 this curve wound from the east end of breakwater towards the Cape, and "near the middle of the harbour there are now but about 16 feet of water, where there were formerly 27 or 28 feet."

During forty years the Author estimates the deposit inside the harbour at 8,200,000 cubic yards, giving an average of 205,000 cubic yards per annum.

Taking the harbour area at 3,500,000 square yards, and average depth 18 feet, or 6 yards, the original harbour-volume was 21,000,000 cubic yards. The shoaling thus represents 38 per cent. of original volume, and the yearly rate over entire area about

[1] This paper is of great interest as giving analogous results to those on the Kentish shore in Dover Bay produced by like artificial causes.—J. B. R.

2·16 inches in depth. "The average depth of shoaling during the forty years will be 7·2 feet. It is not correct to assume that the deposits occurred at this average rate, however, since the shoaling was very rapid during the construction of the works, and has been more gradual since. The scour from the southern end of the breakwater of nearly 300,000 cubic yards represents a portion of the work done by the ebb below the 30 feet curve. It is the result of the 'head,' due to the contraction at this section."

Plans for improvement—Necessity of remedial measures apparent before completion.—The closure of the gap between the ice-breaker and the breakwater was one of the first suggestions. "All the reports since 1836 recommended either the closure of the gap, or its protection by an external apron."

As regards remedies, the Author insists "that no structure should be permitted which creates injurious modifications of the currents." The problem here was "how to protect vessels from the winds, waves, and ice, without interfering with the currents. As the winds and waves generally came from one quarter, and the ice and currents from another, it was apparently separated into these two factors, and the result was the two isolated barriers."

"The principal defect, then, in the plan of the breakwater harbour consisted in placing the ice-breakwater athwart the currents, and so inducing an extensive and protracted shoaling of the harbour."

The Author suggests its removal, and its substitution by floating ice-breakers.

The Gap.—"The greatest scour in the entire harbour is found to be during the last two quarters of the flood-tide, as it runs into the gap past the north-west end of the breakwater. The result is a hole on the outside, just under the end of the breakwater, reaching at one time to 50 feet in depth, and a bar on the inside with only 11 feet of water."

Again he says—"At the end of the ice-breaker is found another 50 feet hole, most of the material from which has gone to the bar, extending from the middle of this barrier to the 11 feet spot, near the north-west corner of the breakwater."

He concludes the gap should be closed, and the ice-breaker removed, "taking the material already at hand, and dumping it into the opening."

He describes the "gorge," or opening between the east end of the breakwater and the shore, the distance ½ mile, and sectional area as 57,168 square feet; in relation thereto he describes two valleys within the enclosed harbour area, "one parallel to the shore, the other near the jetty, with a low, flat spur between them."

He subsequently says—"Here, then, is an instance of a jetty placed in the open sea, scouring out and maintaining a channel of over 30 feet in depth, and for a distance of more than 3,000 feet. It will also be observed that the eddies formed by the currents passing the ends of the jetties have scoured to depths of between 50 and 54 feet. The hole in New York harbour, which we attri-

buted to eddy action, is 52 feet. This would seem, then, to be the limit of such scour under these conditions of velocity and contraction."

He attributes the deep water at the "gorge" to the outset ebb currents.

Enclosing the Harbour.—A close structure to enclose the harbour at its upper end and keep out sediment would exclude the conservative tidal currents; it would produce a current and scour in the portion remaining open, and on completion the flood and ebb at the "gorge" would be equal. The cost of enclosure put down at $1,500,000, exclusive of dredging; the closure of the "gap" put at $500,000 more—in all, $2,000,000, exclusive of dredging. The Author suggests the transfer of sufficient of "ice-breaker" to fill up, and iron caissons, or booms, as protection from ice, opening the harbour to ebb scour, and "could be materially assisted by properly angulated, temporary, or floating jetties and deflectors."

An Act of Congress, passed 2nd August, 1882, to appropriate $125,000 "to commence the work of closing the gap," begun soon after; but frequent delays and official changes, and the Author estimates that at the rate of progress and expenditure to Midsummer, 1885, when 11,500 cubic yards of mattresses and stone had been deposited, or 11 per cent. of the whole, that the cost would mount up to $503,300, and the time to close the gap to twenty-two or twenty-five years. He adds—"The total expenditures from 1829 to 30th June, 1885, have been $2,422,195, and the harbour is almost useless for large draught vessels." He concludes with some caustic reflections on "the present method of doling out the Government appropriations piecemeal for every creek, river, pond, lake, or harbour which may be considered worthy of attention."

J. B. R.

The Ports of the Channel and the North Sea.

By Rear-Admiral Dumas-Vence.

(Revue Maritime et Coloniale, vol. lxxxix., 1886, p. 22, 4 plates and 8 woodcuts.)

This article, which forms the continuation of a report made some years ago, relates mainly to Dunkirk. The conclusions of the previous report are first given in full, and then the condition and projects for the improvement of Dunkirk and the adjacent ports are considered. The previous report winds up by advocating the system of large closed harbours in which the entrances are maintained by the ebb and flow of the tide, on the principle of some English harbours referred to. This is the system which is being carried out at Boulogne, and has been proposed for other northern French ports. Any deposits of silt in the harbour could be removed by dredging. Any interference with the alongshore channel,

between the pier-heads of the Dunkirk jetties and the sandbank beyond, would imperil the access to the port; and it is proposed that a large outer harbour should be formed, with converging breakwaters whose extremities would not project beyond the present pier-heads. Such a harbour would greatly facilitate the access to the docks, would furnish a scouring-basin for maintaining the entrance, and would not interfere with the currents in the roadstead outside.

L. V. H.

The Improvement of Port Empedocle (Girgenti). By G. Rossi.

(Giornale del Genio Civile, 1886, p. 73.)

The town of Girgenti lies in a shallow bay facing south-east and south, having a slight promontory on the south-west. From this a mole was run out in the years 1749 to 1763. This mole is of the shape of the perimeter of a half-hexagon, projecting towards the south-east, turning then to south-west, and finally to the east. Its total length is 1,312 feet. It affords protection from western and southern storms to an area of from 12 to 15 acres of water, having a depth of 10 to 13 feet.

As the prevailing winds are those from the third quadrant, the design of the mole is so far correct, but the basin is open towards the east, and the currents soon brought an accumulation of deposit which reduced the depth. For many years dredging operations were carried on. An opening was made through the mole, in the hope that a stream of water driven in from the westward would scour away the deposits, but this produced no good results.

The port has since 1830 acquired greatly increased importance, owing to the great development of the sulphur industry in the island. The tonnage is now—imports 23,000 tons, exports 133,000 tons. For many years, however, the condition of the harbour was very inconvenient, and even dangerous, owing principally to the silting up, and the problem of dealing with it in a satisfactory manner was a very difficult one. The shore, both to the east and west, is constantly undergoing erosion to a large extent, furnishing abundant material for deposit, which is shifted backwards and forwards by the currents, so that, in whatever direction new breakwaters might be placed, silting up during their construction could hardly be prevented. At the same time it was felt that the port was much too important to be abandoned, and that works for its improvement must be undertaken.

From the year 1830 various proposals were discussed, but it was not till 1867 that new works were actually commenced. It was then decided to construct a breakwater to the eastward of that already existing, of a somewhat similar shape, but much longer, carried out first towards the south to some distance beyond it, then bending first towards the east, and then for a short distance towards the

north west, so as to form with the old work an enclosed harbour with an entrance protected from the southern and south-western winds. The total length of the new work was to be 4,600 feet. Its width at the top was 20 feet at the shore end, and 33 feet at the far end; its height above sea-level from 8 to 10 feet; slopes, 1 to 1 on the harbour side; $1\frac{1}{2}$ to 1 to 2 to 1 on the seaward side.

Owing to disputes with the contractors, and other causes of delay, the progress of the works was very slow. Various modifications were introduced in the design with a view to improving the harbour. In 1875 the breakwater was so far advanced as to project beyond the point at which the old mole protected it from the force of the west and south-west winds, and the result was that these drove the sea against the new work with such violence as to make it rebound into the harbour and force several ships from their anchorage. The silting up also, which had been arrested during the progress of the breakwater up to this point, now recommenced. These effects so alarmed those interested in the shipping-trade that it was considered advisable to stop the works, and re-study the whole question of the harbour.

The result of the new investigations was that the work already under construction was to be prolonged in a south-westerly direction, and a second breakwater was to be built, starting about 650 feet west of the old mole, running out first towards the south, then towards the south-south-west, till it slightly overlapped the other, the two new breakwaters thus enclosing between them a harbour of considerable size, with an entrance, facing south-east, in 25 to 30 feet of water.

The objects to be attained by these works were:—1st. To protect the harbour from the prevailing winds of the third quadrant. 2nd. To place the entrance in deep water, and in the most favourable condition as to silting up. 3rd. To afford easy entrance to ships. 4th. To allow the waves, when driven in from the second quadrant, to flow towards a part of the harbour not required for shipping, and to expend their energy upon the shallow shore opposite the entrance, and avoid all danger of their being reflected back into the harbour proper. 5th. To allow the suspended matter brought by the waves from the west to pass freely away towards the east without depositing in the harbour. 6th. As far as is consistent with the above more important points, to allow suspended matter brought from the east to pass away to the west. The works have now been executed, and are found to answer the purpose for which they were designed.

The slopes given to the breakwater were determined from observations made upon the works previously carried out. The outer slope from the top of the wall (8 feet above the surface of the water), to the depth of 10 feet, was 3 to 1, and from that depth to the bottom 2 to 1. The inner slope was $1\frac{1}{2}$ to 1. These slopes were varied to some extent according to the direction of the wall, so that, when the breakwater faced towards the south, for the upper slope on the outer side $1\frac{1}{2}$ to 1 was found sufficient, and $1\frac{1}{4}$

on the inner side. The width at the top was 33 feet at a height of 8 feet above the water. Four rows of concrete blocks were laid at this level, the blocks (of 350 cubic feet each) being formed *in situ*, laid as headers, the spaces between them being filled in with concrete and rubble.

The Author then describes the method of carrying out the works. The stone was quarried from a neighbouring hill, and conveyed on a line of railway laid down for the purpose on a gradient of 1 in 21. The loaded wagons, after being braked down this incline, were drawn to their destination by engines weighing 15 tons, and drawn back to the quarries by the same engines. Three systems of quarrying were adopted: the first, that of blasting large masses by means of mines charged with from 3,000 to 10,000 lbs. of powder, with the result that from 2 to 2·65 cubic metres of stone were got per kilogram of powder used. The second method was that of drilling 2½ or 3-inch holes at a distance of 30 to 40 feet from the face of the rock, to a depth of 50 feet. Chambers were then formed at the lower ends of these holes, by exploding in them successive charges of powder, beginning with a charge of 1 lb., followed by 6, 25, 88, and 330 lbs. When a sufficient cavity had been formed, a charge of about 3,000 lbs. was introduced, and great masses of rock were thus blown down. The cost of labour was small, and from 3 to 4 cubic metres of stone were obtained per kilogram of powder. Powder was used in preference to dynamite, as it was found more suitable to the nature of the rock. In the third method no explosives were used; the rock was cut and got out by means of picks, wedges, and levers, blocks of over 8 tons being readily obtained with very little waste.

The stone was all delivered on to the breakwater by rail, and a statement is given of the comparative advantages of this system and of that of carrying it out in boats.

Throughout the progress of the works, delay and heavy expenditure has been caused by litigation between the authorities and the contractors, and the latter appear always to have got the best of it.

W. H. T.

Improvement of the Bar of the Senegal.

By — Bouquet de la Grye.

(Comptes rendus de l'Académie des Sciences, vol. cii., 1886, p. 1420.)

The bar of the Senegal is occasioned by the river-water meeting the waves from the ocean; the sand brought up by the latter, and carried forward by a current from the north, is deposited and forms a large circular bar around the mouth of the river. The waves break upon this, rendering the navigation always difficult, and sometimes impossible, from November to May. Ships are often delayed for two months before being able to enter the river. The bar of the Senegal ceases to be dangerous during the summer

of the northern hemisphere, the storms then occurring but seldom, and lasting for a short time only. The waves coming regularly during our winter from one direction, that of north-west, and supporting, so to speak, the mouth of the river, in the midst of moving sands, turns it away more and more to the south, compelling the river to run along the lee shore until the *vis viva* of the ebb tide, which constantly diminishes, becomes inferior to that of the waves. The mouth stops up from the deposit of sand from the outside, the level of the water inside rises, and a new opening is produced, at a point to the north of that which becomes closed, and frequently 12 to 15 miles from it. The oscillatory movement recommences slowly from north to south, quickly from south to north. During the winter season, which in the Senegal lasts from June to October, the river, swollen with the rains, has its water loaded with mud, the bores cease, the bar flattens, and resembles more that of the mouth of the Nile. The improvement of such a condition must be effected in two stages. In the first the movements which have carried the mouth 60 miles away from its natural position must be prevented. The position chosen for the new entrance should correspond with the theoretical definition of the maximum of the quantity of the motion of the ebb tide, and must not be opposed to the commercial necessities of the establishments on the river. The form of the work is given by this quantity of movement, which necessitates the adoption for the southern jetty of a radius of curvature of about 1½ mile. When once the mouth is made permanent, there will be a great improvement in the entrance; but the exterior bar, which has been produced by the deposit of sand, may be removed by directing the ebb tide perpendicularly against the waves from the sea, that is, to the south-west, constructing, to the north of the entrance, a seabank isolated from the mainland. The radius of curvature of this external jetty will also be 1½ mile, and will give a second portion of the "sinusoid" traced by the channel of the river. Under these conditions the waves, which travel from north-west to south-east, carrying with them the sand from the shore, push the sand along the mainland, where it will accumulate on one side, whilst on the other it will be eaten away by the current of the ebb tide. The inner portions of the beach, being incessantly dragged away along the concavity of the northern jetty, will be pushed back eventually by the waves, which will carry them southward. Under these conditions no deposit will form near the extremity of this jetty, and there will be, along the ships' course, depth compatible with the flow of the river.

E. F. B.

The Embankments across the Paradiso and Grottarossa Valleys in Sicily. By A. Croci.

(L'Ingegneria Civile e le Arti industriali, 1886, p. 38.)

In a former Paper,[1] a general description was given of the works executed upon the Sicilian railways in dealing with ground of a very treacherous description. The present article gives particulars of the application of the principles adopted in the case of two lofty embankments. In the case of the Paradiso Valley the ground upon which the embankment was constructed slipped, while in that of the Grottarossa ravine the bank itself failed after its original construction. In both the slipping was caused by the action of water either percolating through the natural ground or soaking into the earthwork and reducing it to a pulpy condition. The Paradiso Valley, where crossed by the railway, is about 1,300 feet wide, the bank being between 30 and 40 feet high. The ground consists of chalky, flinty rock, and in places of chalky marl with foraminifera. The bottom is clay marl of the upper eocene formation. For a depth of 20 to 25 feet it is very pervious, and very compressible, while below it is firm and compact. The first movement took place when the culvert passing through the bank was finished and a part of the earthwork executed to formation level. The culvert was partly destroyed, and a considerable part of the bank was carried away by the moving ground. A series of trial-holes showed that water was passing over the surface which separates the pervious earth from the more compact underlying stratum of marl. Works were evidently necessary for the threefold object of arresting the movement of the upper upon the lower stratum, rendering the upper layers capable of resisting the pressure of the embankment, and partially reconstructing the bank with better materials. A drain was cut right across the valley above the embankment. Where its depth did not exceed 30 feet it was made in open cutting 4 feet wide. A masonry culvert 16 inches square was built at the bottom and the whole cutting filled with dry stone. At greater depths (a considerable portion being about 55 feet deep) shafts were made at intervals, adits were driven from shaft to shaft, a similar culvert was built along them, and a quantity of dry stone was filled in over the culvert and up to the top of the shafts. From this main drain four transverse drains, constructed in the same way, were carried across the seat of the embankment, discharging at a considerable distance below it into the valley. All these drains were carried down into the solid ground as determined by the trial holes. A series of ten more drains were cut through the seat at various angles, discharging by collecting drains into the main stream.

The bank itself was to a large extent reconstructed with selected

[1] Minutes of Proceedings Inst. C.E., vol. lxxv. p. 343.

materials, and the slope on the down-stream side was formed with four benches, the lowest 30 feet wide, the highest 5 feet. A masonry 5 feet culvert passes through the embankment, and a masonry channel is prolonged to a distance of more than 150 feet beyond the toe of the slope. The foundations of the culvert are carried through the slipping ground down to the solid, and three curtain walls, at distances of about 55 feet apart in the line of the channel, are also carried down to the solid. Ditches lined with masonry are formed along the foot of the bank on both sides. The works required a considerable time for their execution; the first slips occurred in the autumn of 1876, and the works were not finished till February 1879. During their construction the line was carried along a diversion, which was so injured by further slips that a second had to be made, long timber scaffoldings being adopted in each case.

The cost of the work is given as: for the culvert, £3,900; for the diversions, £3,000; for the new earthwork in the embankment, excavations, and stonework in drains, £17,500; the total cost being at the rate of about £60 per lineal yard of line.

The Grottarossa ravine is crossed by the railway on an embankment 650 feet long and 52 feet high. The sides and bottom of the valley are formed of siliceous limestone of the miocene period, which has been exposed by the denuding action of water. The seat of the embankment is, therefore, perfectly stable, and capable of resisting the pressure upon it. In constructing the bank, the central portion was made up of clayey material run out from the adjacent cutting in wagons, while the slopes were made up later on of rocky detritus from the foundations of a station at the other end of the bank, and to this careless method of construction the failure of the work was doubtless due to a considerable extent.

Soon after the opening of the line the slopes on both sides of the bank began to slip away. A section is given showing that the lines of slip on each side coincided very nearly with a cycloidal curve formed by a rolling circle, having for its diameter the height of the bank, and for origin the commencement of the slip at its top. In repairing the work the material which had slipped was cleared away, massive counterforts of dry stone standing on masonry drains were built deep into the solid part of the bank, at intervals of 30 or 40 feet; three benches were formed with stone drains running along them on one side, and two benches on the other. At the foot of the slope on each side a ditch lined with masonry was formed. The cost of the works amounted to £30 per lineal yard of embankment. The Author, having lately revisited the works, found them in excellent condition.

The Paper deals also with the general subject of earthwork construction in treacherous ground, and is illustrated by a number of sections of the work.

W. H. T.

On the Results obtained in seeking for a Supply of Pure Subsoil Water for Berlin.[1] By Professor Dr. FINKENER.

Four trial-wells were sunk near Berlin, denoted as A, B, C, and D. The water when drawn was clear and colourless, but on standing for a quarter of an hour the samples manifested a whitish opalescence, and in A, D, and B, a reddish deposit was formed. A depth of 10 inches of the water from C was found to impart a cloudy whiteness to the bottom of a glass vessel. Corresponding with these appearances the beds of the watercourses fed by A, D, and B, were of a reddish colour, which was not the case with that from C. The water from A was palatable; B and D when freshly pumped had a taste of iron, and were insipid; the insipidity of C was less marked. Analyses of each sample are set forth in a Table, and the Author compares them with the water from the Spree and the Havel. After long continued pumping the percentage of mineral matters in A, C, and D, increased; in the case of B it sank at first, but subsequently remained constant. The chlorine increased in A and D, sank in B, and remained constant in C. The amount of lime remained constant in A, became diminished at first in B, but was afterwards constant, and rose in C and D. Iron increased in A and C, but sank in B and D. Silicic acid rose in A and C, but decreased in B and D. Sulphuric acid increased in A and C, but remained constant in B and D. The oxygen became augmented in B and C, but rose and sank again in D, fell at first in A, and then increased in volume. As the result of the continuous pumping for three months, all the water became more or less changed in character, but the changes were not uniform. The Author discusses exhaustively the movements of water through homogeneous sand, from one confined space to another; the movements of water in natural soil; the movements of water towards a spring or well in uniform strata, and through strata of variable character. The chemical changes which water undergoes in its passage through the soil are described, and it is shown that rain-water entering the ground with 6 cubic centimetres of oxygen to the litre is gradually deprived of its oxygen by the decaying vegetable matters in the superficial layers of soil, and absorbs carbonic acid gas. It is thus enabled to attack the débris of the silicates, and dissolves lime, alkalies, and also silicic acid, and with its still remaining oxygen converts the protoxide of iron into peroxide. As it sinks lower into the soil it loses all its oxygen, and can now dissolve protoxide of iron from the silicates; and if it still contains organic matter in solution it may convert the peroxide of iron into protoxide. The richer it is in carbonic acid the more energetically does it lay hold on the silicates. The carbonic acid is of course derived from the oxidisation of organic matters, and as these also bring iron into solution it naturally follows that water which has

[1] The original is in the Library of the Inst. C.E.

traversed a soil rich in humus yields for both reasons a liquid richer in the protoxide of iron than that which has passed through a sterile soil. Moreover, the sulphate of lime dissolved in the water is deprived of part of its oxygen, and is converted into sulphide of calcium, and this again is broken up by the carbonic acid, and is converted into carbonate of lime and sulphuretted hydrogen. But this latter state of things can only exist in water which is no longer in contact with strata containing hydrated peroxide of iron. The changes brought about in the circulation of the water in a given district caused by pumping are discussed; and it is stated in conclusion that a selected area only yields a suitable drinking water when the trial-well becomes filled from the outset with usable water. It is likewise indispensable that the water should be free from the protoxide of iron.

G. R. R.

Report on the Search for a Pure Supply of Spring-water[1] *for Berlin.* By C. Piefke.

It having been resolved by a commission, appointed by the Municipal Council of Berlin, to carry out a series of experiments in the tract of country between the Spree and the Dahme, in order to ascertain the possibility of procuring thence a supply of drinking water for the City of Berlin, the author details the results of these trials, made during the course of the year 1884. By reference to a coloured map the position of the various trial-holes and sinkings is explained. The total length of the various borings was 799 metres, divided amongst twelve wells, and fifty-seven stand-pipes for observing the level of the subsoil water. In the course of the inquiry an accurate survey was made of the stratification and of the character of the different beds of sand passed through. The mechanical properties of the sand are considered at great length, and the fluctuations in the level of the subsoil water, as also its chemical composition, and the nature of the impurities therein, are set forth in detail.

The bore-holes in the alluvial and diluvial soil of the valley of the Spree and of the Dahme never exceeded 25 metres in depth. Over nearly the entire area, at a depth of about 10 metres below the bed of the valley, is a layer of gravel, situated between the coarse and the fine-grained sand, which varies but little in thickness, and forms the water-bearing stratum of the district. Between 4 and 5 per cent. of the area was covered with peat bogs or morass. Analyses are given of the different beds of sand, and a special series of experiments was carried on to test the relative proportions of the different oxides of iron present in the soil at various depths. It was found that in nearly all cases the quantity

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[1] The original is in the Library of the Inst. C.E.

of peroxide of iron gradually decreased with the depth until it disappeared, while the protoxide of iron increases in like proportion; and the Author points out that the transition of the iron from the state of peroxide to protoxide marked the gradual exhaustion of the oxygen in the subsoil water, until the depth is reached to which no oxygen can penetrate. In the upper strata the sand is ruddy in colour, and the particles of quartz, when seen under the magnifying glass, appear dull and coated with a pigment. Below the border line the sand grains are gray in colour, and this change represents approximately the limits of the oxygen-zone throughout the district. Next in point of importance, from a hydro-geological point of view, is the contents of the sand-layers in lime, which in the diluvial sand varies from 2 to 3 per cent. The percentages of carbonate of lime in the sand at various depths are set forth in a Table. Traces of the gradual impoverishment of the soil in lime, as the beds approach the surface, are clearly seen in the analyses. The organic matters found in the soil have a somewhat important bearing also on the question.

In discussing the mechanical properties of the sand-layers, the Author shows the percentage of each layer in grains of $\frac{1}{10}$ millimetre and upwards in diameter, varying from 3 per cent. of the finest grains in the gravel to 80 per cent. in the very fine sand. The circulation of the subsoil water at different depths is discussed, and the direction and speed of the underground currents, and the rapidity with which the water moves at various depths, and in the different kinds of sand encountered in the numerous trial wells, are exhaustively dealt with. The available proportion of the rainfall of the district is examined, and the Author sums up in conclusion the qualities peculiar to the water of the locality as follows: (1) A variable but never absent percentage of iron in an unstable form, and one readily decomposed on exposure to the air. This gives rise to the turbidity of the water after it is drawn, and while it may often occasion a scarcely perceptible blueish opalescence, at other times it gives rise to the separation of copious brownish flakes. All surfaces exposed to the action of the water become sooner or later coated with an incrustation. (2) Where iron is abundant there is associated with it, as a rule, a considerable quantity of dissolved organic matter, due to the excess of impurities in the soil beyond its power of oxidization. (3) Coincident with the above conditions is the presence of a notable quantity of sulphuretted hydrogen, in many cases scarcely perceptible to the sense of smell, though in others sufficient to cause the water to to be offensive. (4) In the best samples of water there is a marked absence of carbonic acid gas, and in the worst samples there is an excess of this gas. These results the Author considers to be owing to the nature of the mineral constituents of the soil, and the character of the peaty matters present in certain districts. It would be impossible, except by chemical processes, to free the water from the above-named impurities.

G. R. R.

The Spongilla in Main Water-Pipes. By Desmond Fitzgerald.

(Transactions of the American Society of Civil Engineers, 1886, p. 337.)

Passing by, meantime, the question of the growth and development of the spongilla in lakes, reservoirs, &c., the writer calls attention to the fact of the growth of the *spongilla lacustris* in the pipes of a water-system. When the sponge is present in the sources of supply, pieces of it find their way into the pipes. These, decaying, give an offensive cucumber- or fishy-taste to the water. The sponge is really an animal, and lays eggs, which float down with the water, and attach themselves in large quantities to the interior surfaces of the pipes. The eggs mass themselves in traceries like lacework. Sponge is brought forth, and grows in circular patches of green. Large mains, under a pressure of 100 feet, have been filled with offensive masses of sponge closely packed between and around the tubercles. Flushing does not remove this growth, and it results in an increase of the taste. Scrapers or wire-brushes are necessary.

D. K. C.

Breyer's Micro-Membrane Filter. By Dr. F. Renk.

(Gesundheits-Ingenieur, 1886, p. 419.)

Additional particulars are given respecting this filter.[1] The construction of the gratings on which the sheets of filtering material rest is explained by reference to illustrations. These gratings are stamped out of sheet brass, and are then nickel-plated. They are prepared in duplicate, and are soldered together so as to preserve a small space between them, having outlet-pipes on either edge. Sheets of fine wire-gauze are then attached to the exterior of the gratings, to serve as supports to the filter-sheets. Upon these gauzes the filter-sheets are stuck by means of a solution of shellac in spirits-of-wine, or caoutchouc dissolved in benzine. The preparation of the sheets, which requires great care, is explained in detail. For this purpose the best glossy, fibrous asbestos is first reduced to a fine powder. This powder is then made into a thin slip with water and crystalline carbonate of lime, and is again ground in a special mill. The lime is subsequently dissolved out by means of hydrochloric acid, in consequence of which treatment a still further separation of the particles of asbestos is effected, and the mass is then carefully washed. An illustration shows the extreme minuteness of the fibres of asbestos thus treated, as compared with silk, spider's web, and spun-glass, each multiplied

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[1] Minutes of Proceedings Inst. C.E. vol. lxxxv. p. 470.

1,000 diameters. This emulsion of asbestos is formed into thin leaves by suspending it in a vessel of water, at the bottom of which is a sheet of fine tulle, strained over a wire gauze in a movable metal framework. The water is allowed to flow away, through an orifice at the bottom of the vessel, with a suction varying from 1 to 10 metres. When the leaf becomes of the proper thickness, owing to the deposit upon it of asbestos particles, it is lifted out on the gauze and dried at 150° Centigrade. The tulle then enables it to be taken off the wire-gauze, after which it is cut up into sheets of the proper size.

The filter-plates thus formed are finally fastened, tulle downwards, against the wire-gauze on the gratings. Illustrations are given to show each process. Special arrangements of the apparatus have been devised for the use of troops, tourists, &c., also for application on a large scale, for which latter purpose several series of gratings are fixed side-by-side in a tank, the exit-pipes from each chamber being led into a delivery-pipe common to all. Breyer can in this way prepare a filter capable of yielding 30,000 litres of water per hour. Filters are also furnished, which can be used under a high pressure such as occurs in an ordinary town-supply. These have a slightly modified arrangement of the filter-chamber.

G. R. R.

Calculation of the Profile of Masonry Reservoir-Dams.[1]

By — Hétier.

(Annales des Ponts et Chaussées, 6th series, vol. xi., 1886, p. 615, 9 woodcuts.)

In a recent article, the Author pointed out the necessity of considering the pressures in the oblique sections of retaining-walls, for which empirical methods of determination were given;[2] and the present article supplements the preceding one by furnishing a method of calculating the exact profile of a reservoir-dam, with the inner face vertical, by considering oblique sections of maximum pressure. After a careful analytical investigation of the question by the aid of diagrams, the following conclusions are arrived at. As the smallest fissure in a masonry reservoir-dam is dangerous, no tensional strains should be admissible; and for dams not exceeding 115 feet in height, the profile may be the curve of equal nullity of tension determined by horizontal sections. For large dams of greater height, the pressures in oblique sections must be taken into consideration; and in the case of a vertical inner face, the outer profile may be determined by the method given in the article. A section of a special example of dam investigated, where the head of water is 164 feet, the tension nil, the greatest pressure

[1] Minutes of Proceedings Inst. C.E. vol. lxxxiv. p. 458.
[2] Annales des Ponts et Chaussées, 6th series, vol. ix. p. 795.

7·4 tons per square foot, and the weight of the masonry 1½ tons per cubic yard, shows to what extent the profile calculated from oblique sections of maximum pressure differs from the profile determined by horizontal sections. On the inner face, there is neither pressure nor tension down to a depth of 131 feet below the water-level; but beyond this depth, the masonry is exposed to slight pressures. On the outer face, the pressure increases down to 83½ feet below the water-level of the reservoir, where it attains 7·4 tons per square foot, and, with the calculated profile, continues constant down to the bottom. The outer face, however, of the dam, whose profile is determined by horizontal sections, is exposed to greater pressures below the 83½ feet, for its width is less beyond this point than the calculated section, amounting to a maximum reduction in width of about 14 feet, out of a total width of 99 feet in the calculated section, at 121½ feet below the water-level of the reservoir, and diminishing again to a difference of only about 5 feet, out of a total width of 129⅔ feet at the bottom, 164 feet below the water-level.

L. V. H.

The De-Ferrari-Galliera Aqueduct at Genoa.

By L. Mazzuoli, Engineer.

(Annali di Agricoltura 1885, Florence 1885, p. 118.)

By the completion of the De-Ferrari aqueduct, Genoa not only receives an additional supply of water, but a large amount of motive power is now available in the valley of the Polcevera for manufacturing purposes. The supply for this aqueduct is obtained from a large reservoir which has been constructed in the upper part of the Gorzente, a torrent the waters of which, flowing into the Orba and Bormida, ultimately reach the Po. This reservoir was formed by throwing a masonry dam, 150 metres (492 feet) long; 30 metres (98·42 feet) thick at base; and 7 metres (22·97 feet) at top, across the valley. The geological formation of this district belongs to the lower trias, the site of the reservoir being serpentine. The artificial lake so formed covers an area of 262,000 square metres (64·71 acres), the top-water level being 650 metres (2,132 feet) above the sea. Its available capacity is 2,835,000 cubic metres (100,120,860 cubic feet), and the area of the natural catchwater basin by which it is supplied is 17,687,500 square metres (4,368·81 acres). A tunnel driven at a depth of 20 metres (65·61 feet) below top-level serves as outlet to the reservoir, and passes under the Apennines in a south-easterly direction for a distance of 2,283 metres (7,488·24 feet). In making this tunnel a considerable quantity of water was met with, and which, now considerably diminished, still yields about 50 litres (11 gallons) per second. From the south-east end of the tunnel the

water is conveyed to Genoa by a line of cast-iron mains 20 kilometres (12·43 miles) in length, and 60 centimetres (23·62 inches) in diameter. The thickness of these pipes varies from 0·016 to 0·032 metre (0·63 to 1·26 inch), and are subject to a maximum pressure due to a head of 136 metres (446 feet), which can eventually be increased to 250 metres (820 feet). The maximum discharge of this aqueduct is 375 litres per second (82·5 gallons).

P. L. N. F.

The Sewerage and Irrigation Works of Berlin for the year ending the 31*st of March*, 1885.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1886, p. 255.)

The record of the further progress of these works shows that two thousand and six additional house-connections have been made, and the number of inhabited areas drained into the various systems is now fourteen thousand two hundred and forty-one. In the Radial Systems I. to V., the total volume of sewage-water for the twelve months was 32,484,783 cubic metres, or a daily volume of 89,000 cubic metres, equivalent to 100·28 litres (22 gallons) per head of the contributory population. The working expenses of the interception system attained a total of 594,903 marks (£29,745), distributed as follows:—

	Marks.
General management	34,057
Pumping-stations	346,344
Street-mains and house-connections. . . .	214,502
Total . . . . Marks	594,903

Of the total area of land acquired for irrigation-purposes for Radial Systems I. to VII., amounting to 4,453 hectares, 3,156 hectares or 70·9 per cent., have been prepared for irrigation, and 2,252 hectares of this latter surface, equal to 71·3 per cent., have been systematically drained.

An analysis of the various crops grown on the farms is given, among which cereals were raised on 1414·68 hectares, and 1230·91 hectares were allotted to meadow-land. The entire area of the various properties round Berlin devoted to the treatment of the sewage-water is 5374·49 hectares; of which 3142·98 hectares have been prepared for irrigation, and 1469·62 hectares are cultivated in the ordinary way. The results of the sales of produce from the meadows, garden-plots, and reservoirs are given in detail. The weight of grass has in all cases exceeded that of the previous year, and ranged from 15·27 centners per are on the Falkenberg farm, to 9·71 centners per are at Heinersdorf. In the garden-plots hemp and chicory were grown to a large extent, also beetroot

and market-garden produce. The area of the reservoirs has been considerably extended, and crops of hemp, rye, wheat, beet, &c., have been grown on them with fair profit. The cost of the irrigation-works are set forth as follows:—

	Marks.	
Receipts from the irrigated areas . .	1,608,310·17	
Expenses of working	1,662,684·87	
Sinking fund	165,264·00	
Interest on capital	366,226·97	
Unforeseen expenses	8,836·52	
Marks	2,203,012·36	
Excess of outlay on receipts	594,702·19	(£29,735)

The gross receipts and expenditure upon the entire outlay for drainage and sewage disposal, amounting to about 64 millions of marks, are thus stated:—

	Marks.	
Receipts	3,292,341·93	
Expenditure	5,067,672·79	
Making the year's cost . . Marks	1,775,330·86	(£88,766)

The chemical investigation of the sub-soil drainage from the irrigation-works to the south of Berlin, has been undertaken by Dr. Salkowski, and out of nineteen sets of samples examined by him, all but one complied with the requisite conditions, as respect purification, and demonstrated that the process had been perfectly satisfactory. The effluent from the reservoirs was again this year open to objection in point of quality. Samples from the areas to the north of Berlin have been regularly tested, and the results, though inferior in point of purity to those on the south of the city, are considered favourable. The health of the population of the district under irrigation has been very good; among the 775 men, 277 women, and 414 children, there were 412 cases of illness, and 23 deaths. The death-rate of 15·7 per thousand was thus little more than half that of Berlin, which amounted to 26·5 per thousand for the year 1884.

G. R. R.

Disinfecting-Stoves. By O. Courtois-Suffit.

(Nouvelles Annales de la Construction, 1886, p. 97.)

Whatever theory may be propounded with respect to the manner in which contagious diseases are propagated, there can be no doubt as to the fact that the clothes and linen soiled by the patient contain numerous sources of infection, and it becomes important to public authorities to be in possession of methods of disinfection capable of destroying all possible germs and virus in any objects

requiring to be thus dealt with, and to be able to do so without injury to the linen. Though chemical processes might be adopted in certain cases, they would not, for such a purpose as this, be equally efficacious as heat applied for a sufficient time and under proper precautions. Numerous systems have been proposed in which heat is employed for this purpose, and the Author shows how they have in various ways failed to accomplish the object in view. Nothing has been so successful as high-pressure steam, and the Author states that some experiments have been recently conducted by a scientific commission, appointed by the French Government sanitary authorities, with the stoves designed by the firm of Geneste and Herscher, of Paris. These experiments were supplemented by others conducted in the laboratory of Mr. Pasteur. The Commission reported that, "The stove supplied with high-pressure moist steam (*vapeur humide*), manufactured by Messrs. Geneste and Herscher, of Paris, is an excellent disinfecting apparatus, and it is only necessary to raise the temperature in this stove to 106° Centigrade (which can readily be done), in order to destroy effectually every pathogenic germ, even in the centre of a mattress; it is worthy of the utmost confidence, and its use is recommended wherever it is possible to set it in operation." By reference to diagrams, the construction of this apparatus is explained. It consists of a wrought-iron cylinder, 2·25 metres in length and 1·3 metre in diameter, with special arrangements for the generation, in a detached boiler, of the supply of steam, as also for the introduction and removal of the linen to be treated. The working of the disinfecting process is explained; the time required for the disinfection of a bulky substance, such as a mattress, is fifteen minutes. In addition to this, twenty minutes suffice for the subsequent dessication, and a few minutes are needed for putting in and taking the things out of the stove. The drying is done in the stove itself by simply opening the door of the chamber.

G. R. R.

Frager's Water-Meter. By Colonel Goulier.

(Bulletin de la Société d'Encouragement, 1886, p. 116.)

The water-meters, on Frager's system, constructed by Mr. Charles Michel, are on the positive principle of direct measurement; two vertical cylinders side by side with reciprocating pistons. The pistons, one to each cylinder, have no rods, and are made specially deep enough to guide themselves. They are fitted each with two washers or disks of india-rubber in contact, the free edges of which spread upwards and downwards against the interior of the cylinder. Each disk is thus fairly placed to oppose the pressure of the water alternating above and below the piston, and under this pressure to lap closely on the surface of the cylinder, and make the piston water-tight. The cylinders are separated by a

partition from the "cap," or upper chamber, in which the distribution of the water is effected. Above each cylinder there are three ports, analogous to those of an ordinary steam-engine cylinder, with a slide-valve, which is reciprocated vertically by means of a rod passing through a stuffing-box in the partition, and commanded by the piston. The piston is formed with a trunk, which is closed at the lower end, in which the valve-rod is located. When the piston ascends, and arrives near the end of its upward stroke, it taps the valve-rod, lifting it to the extent of from ¼ inch to 1½ inch, according to the size of the meter, and so shifting the valve in the upper chamber. When the piston arrives near the end of its downward stroke, a ferule on the lower end of the valve-rod is caught by the upper end of the trunk, and the valve is shifted downwards. The middle ports under the valves are always covered, and in free communication with the discharges, whilst the extreme ports by which the water is admitted, are in communication, not with the cylinder directly under them, but with the alternate cylinders; and thus each piston moves the valve for the admission and discharge of water to and from the neighbouring cylinder.

Each period, or cycle of operations, thus comprises four alternate movements of pistons, during which four cylinderfuls of water pass from the entering-pipe into the discharge-pipe. A head of pressure of 1 metre, equivalent to 1·43 lb. per square inch, suffices to keep the meter in action. The apparatus works automatically, without requiring any lubrication. The registration of the number of periods is effected by means of a finger on the upper end of one of the valve-rods, by which a rachet-wheel is turned by one tooth at each descent, whence the movement is transmitted by suitable gearing to the needles of the counter.

The system of meter just described, having vertical cylinders, is an improved modification of a like system in which the cylinders are horizontal. Of these, upwards of 60,000 have been manufactured.

D. K. C.

Rating of a New Type of Gyrometer, called hitherto a Hydro-Dynamometer.[1] By — DE PERODIL.

(Annales des Ponts et Chaussées, 6th series, vol. xi., 1886, p. 773, 1 plate.)

The Author proposes to call this instrument henceforward a gyrometer, since it measures the forces of gyrations or eddies. This new type of instrument is more convenient and exact than the one previously described,[2] and drawings of it accompany the article. The rating experiments were made with three different

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 430.
[2] Annales des Ponts et Chaussées, 5th Series, vol. xix. p. 11.

sizes of palettes, or disks,[1] and the results are given in a table, in which the angle of torsion is expressed in grades or hundredths of a right angle, and the number of grades is represented by N. The velocity of flow is $0 \cdot 034 \sqrt{N}$ for the large palette, $0 \cdot 103 \sqrt{N}$ for the medium palette, and $0 \cdot 310 \sqrt{N}$ for the small palette. The values of the coefficient K, for each palette, calculated by a formula given in a previous article,[2] are 1·38 for the large palette, 1·18 for the medium palette, and 1·01 for the small one. Before comparing the angles of torsion with the velocities of flow producing them, it was ascertained that they were exactly proportional to the turning forces applied to the instrument. If there were three similar gyrometers, one a fifth of, and another five times larger than an intermediate one, so that in homologous dimensions a, b, c, the relative proportions, $25\,a = 5\,b = c$, always existed, and forces P_a, P_b, P_c were applied to each, such that $25^2\,P_a = 5^2\,P_b = P_c$, the three homologous displacements $f_a\ f_b\ f_c$ would be such that $25\,f_a = 5\,f_b = f_c$. As the forces P produce the same angle of torsion, it is evident that, disregarding the variation of the coefficient K, the three forces would be due to the same velocity of flow, since the pressure on a palette is proportional to its surface; and consequently the three gyrations would serve to measure velocities within the same limits, provided the three corresponding series of three palettes were retained. By diminishing, however, the palette in the large gyrometer, greater velocities could be measured; whilst by increasing the palette in the small gyrometer, smaller velocities of the flow of water could be measured, or even of a current of air; so that the former could serve for navigation on the sea, and the latter in the air. As the angle of torsion must not be large enough to alter the elasticity of the steel wire, its arc must be less than double the radius, or an angle of 127·3 grades, so that 80 grades is a safe limit. If the larger of the three assumed gyrometers was fitted with the small palette of the intermediate gyrometer, having a diameter of 1¼ inch, it could measure a velocity of 102 feet per second, or 60 knots an hour, which is about four times the speed of steamers. On the other hand, if the small gyrometer was fitted with a palette homologous to the small palette of the intermediate gyrometer, namely, with an arm of 0·39 of an inch in length, and a diameter of ¼ inch, a maximum velocity of flow could be measured of 9 feet per second in water, and 288 feet per second in air. If the greatest velocity of an aerial machine did not exceed 12½ miles an hour, or 18¼ feet per second, the palette could be given an arm of 2¼ inches, and a diameter of 1·53 inches.

L. V. H.

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[1] From the drawings, it appears that the diameter of the large palette is about 5 inches, of the medium palette 2½ inches, and of the small one 1¼ inches.—L. V. H.

[2] Annales des Ponts et Chaussées, 5th Series, vol. xiii. p. 472.

On the Heat of Combustion of Coal.

By — Scheurer-Kestner, and — Meunier-Dollfus.

(Annales de Chimie et de Physique, vol. viii., 1886, p. 267.)

About the year 1870 the Authors made experiments on the heat of combustion of coal, and drew attention to the circumstance that this cannot be calculated even approximately from its chemical composition. Dulong's formula, which makes allowance for the hydrogen in the form of water in coal, gives results too low; whilst if all the hydrogen is taken credit for, the results of calculation are sometimes below, and at others above those of experiment. In their previous experiments, the Authors used the coal in the form of powder; in the present case, in small pieces, in which state the coal burns more easily in the calorimeter. The gases used (compounds of oxygen and nitrogen) to burn the coal were always carefully dried, and the cinders were weighed after combustion. The present results confirm those previously recorded. The coals experimented upon were of the most various character, the carbon ranging from 96·66 to 76·87; the hydrogen from 5·1 to 1·35, and the oxygen, nitrogen, and sulphur from 18·45 to 1·99 per cent. The Authors give a complete Table of the results of their experiments, and compare them with the heat of combustion according to Dulong's formula. The lowest result, 8,259 Centigrade units (pure carbon being 8080), was obtained from a coal having the largest proportion of carbon, 96·66; the lowest of hydrogen, 1·35, and the lowest of oxygen, nitrogen, and sulphur, 1·99; whilst the highest, 9,623, from one having 88·48 of carbon, 4·41 of hydrogen, and 7·11 of oxygen, nitrogen, and sulphur. Only 9,163 units were obtained from a coal of the composition 89·96 carbon, 5·09 hydrogen, and 4·95 oxygen, nitrogen, and sulphur, which from its chemical analysis would appear to be a superior coal to the previous one.

E. F. B.

Steam-Boilers and Furnaces.

(Compte rendu des Séances du 9^me^ Congrès des Ingenieurs en chef des Associations de Propriétaires d'Appareils à Vapeur, in November 1884. Paris, 1886.)

The ninth congress of Engineers of Steam Users' Associations in France and Alsatia, was held in Paris in 1884; Mr. Walther-Meunier, president. Twenty-two questions were raised for discussion.

The first question, on the employment of steel in the construction of steam boilers, was held over. The second question related to the deformation of one of the heaters (*bouilleurs*) of a French

boiler, over the fire, immediately in front of the bridge. The boiler was constructed of steel. The drift of the discussion appeared to show that the deformation, or downward bulging of the plate, was caused by overheating due to deposit of sand, and to a less extent to the unusual height of the bridge. It was maintained that considerable deposition of sand generally takes place in the heaters, in the neighbourhood of the forward communicating-pipe, which rises from the heater to the boiler. The forward pipe, in this case, was over the back part of the furnace, and so conduced to the accident. The president remarked that in Alsatia, the communicating-pipes are all placed behind the bridge, and that he had found deposits 16 inches in advance of them.

The third question related to the Orvis furnace (*post*, p. 449). The fourth question dealt with mechanical stokers in England, in a communication from Mr. Walther-Meunier, prefaced by remarks on the Ten Brink and Schultz-Roeber furnaces, already noticed.[1] After describing the mechanical stokers of Proctor, Bennis, Vicars, Henderson, Taylor, Knap, MacDougall and Sinclair, the speaker summarised the opinions of certain English experts as follows:—Mechanical stokers are serviceable when continuous and regular work is required, and at collieries for burning up the sweepings. For smoke-prevention they are not satisfactory where the fires are pushed. Where the demand for steam is variable, it is necessary to supplement the mechanical stokers with boilers fired by hand, in the ratio of one for every three boilers mechanically stoked. These were identically the conclusions already arrived at on the Ten Brink and Schultz-Rocher furnaces. The speaker testified to the efficiency of alternate side-firing, first recommended by C. Wye Williams, giving the results of observations he had made on the firing of a battery of three Lancashire boilers in Manchester. The stoker, going from right to left, charged the left side of each of the six fire-grates; then similarly charged the right side of each grate. Air was admitted at the bridges. The consumption of coal was at the rate of 2,132 lbs. per hour, or 19½ lbs. per square foot of grate per hour—charged every ten minutes. After each charge, very light grey smoke was emitted, lasting two minutes twenty seconds. The air was admitted through fifteen circular orifices about $2\frac{5}{16}$ inches in diameter, giving a total area of 106 square inches, or 5·8 square inches per square foot of fire-grate, which was 18·16 square feet in area. Mr. Bour stated that in Germany the combustion of lignite without smoke with mechanical stoking was only effected by the admission of a large excess of air; for it was found that whilst in ordinary furnaces 25 per cent. was sufficient, with mechanical stokers an excess of from 100 to 250 per cent. was admitted.

The fifth question bears upon the Ten Brink furnace. Mr.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxiv. p. 345; vol. lxxvii. p. 438.

Walther-Meunier states that, in Alsatia, all the furnaces of this construction have been removed and abandoned, in consequence of the labour and inconvenience of management, and the absence of economy of cost for fuel; but that the prevention of smoke was completely effected.

Question twelve relates to a trial of Quiri's portable engines, already noticed.[1]

Question fourteen deals with the results of the trials of a Corliss engine at Creusot, already noticed.[2] In the course of the discussion Mr. Cornut insisted on the advantage of sufficient compression of steam in the cylinder to counterbalance and bring to a state of rest the reciprocating members, and to minimise the stress on the foundations. The compression, he maintained, should be a function of the velocity and the quantity of matter in movement.

Other questions deal with Pindray's furnace, having expanding flues and very deep fire-bars; several systems of removable tubes; systems of heating feed-water; and Perret's immersed fire-grate.

D. K. C.

Performance of the Orvis Furnace for Steam-Boilers.

By H. Walther-Meunier.

(Bulletin de la Société industrielle de Mulhouse, 1886, p. 135.)

According to the Orvis system of furnace, air is introduced into the fireplace above the fuel, through three tubes at the front, over the doorway. The outer ends of these tubes are directed downwards. A jet of steam at the bend of each tube is discharged through the horizontal limb into the furnace over the fire, so as to draw and drive currents of air into the fire amongst the smoke, with the object, at the same time, of accelerating the draught over the bridge.

The Orvis system was applied to a battery of four steam-boilers, at the factory of Messrs. Hartmann, Son and Co., Munster, having a total heating surface of 2,014 square feet, provided with a Green's Economiser of two hundred and twenty-four pipes. Trials were made before and after the application of the Orvis system. First, on the 8th, 9th, and 10th of December, 1885; and secondly, on the 15th, 16th, and 17th. The steam for the service of the Orvis apparatus was supplied and measured from a separate boiler.

The coal used was Ronchamp, Griesborn III., and Petite Rosselle III., in the proportion of one-fifth, three-fifths, and one-fifth respectively. The leading results of the two series of trials were as follows:—

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 388.
[2] *Ibid.* vol. lxxx. p. 425.

—	Before.	After.
Total quantity of coal consumed, net weight, deducting ash, clinker, and humidity	lbs. 26,239	lbs. 23,984
Water as at 32° Fahrenheit, evaporated into steam of 4·20 atmospheres	215,802	216,117
Water evaporated per lb. of net weight of coal	8·245	9·018
Steam consumed by the Orvis apparatus	..	9,438
Coal consumed by the Orvis apparatus, assuming an evaporation of 8·45 lbs. of water per lb. of coal	..	1,144
Total weight of coal consumed during the working of the Orvis system	..	25,128
Difference in favour of the Orvis system	..	1,111
" " " " as a percentage	..	Per cent. 4½
Smoke after each charge of coal lasted:—	Min. Sec.	Min. Sec.
Black	4 2	..
Brown	..	1 21
Light or clear	7 0	2 41
Analysis of the burnt gases, between charges:—	Per cent.	Per cent.
Carbonic acid	7·95	8·22
Oxygen	11·11	10·54
Carbonic Oxide	0·00	0·00
Analysis of the burnt gases, average sample:—		
Carbonic acid	7·47	7·81
Oxygen	12·46	10·49
Carbonic oxide	0·00	0·00
Temperature of the burnt gases on leaving Green's economiser	Fahrenheit. 385°	Fahrenheit. 417°

From the above results it appears that, making allowance for the steam consumed by the Orvis apparatus, a net economy of 4½ per cent. of fuel was effected. Omitting this allowance, the actual evaporative efficiency with the Orvis system was to that without the apparatus as 9·018 to 8·245 per cent., or 9·4 per cent. more. Yet combustion was complete in both cases, there being an entire absence of carbonic oxide gas.

The foregoing trials were made in consequence of results, apparently contradictory, which had been obtained from previous trials with the Orvis apparatus, conducted in 1884 by Mr. Walther-Meunier.[1] The first of these trials was made on the 3rd and 4th of September, 1884, at Bâle, on an ordinary boiler of the French type, well attended to and well worked. The coal used was Sarrebruck. The boiler was worked on the first day without the Orvis apparatus, and on the second day with it.

	1st Day.	2nd Day.
Coal, as dried, consumed per square foot of heating-surface per hour	0·49 lbs.	0·63 lbs.
Coal, as dried, consumed per square foot of fire-grate per hour	8·74 "	11·25 "
Water, as at 32° Fahrenheit, evaporated per lb. coal, as dried	6·25 "	5·19 "

[1] The results of these trials are published in the "Compte rendu des Séances du 9me Congrès des Ingenieurs en Chef des Associations de Propriétaires d'Appareils à Vapeur," November 1884.

Showing less efficiency for the Orvis apparatus. The degrees of smoke prevention were the same on both days. The Orvis apparatus consumed steam at the rate of about 300 lbs. per hour.

A series of comparative trials, of twelve hours each, was made in October and November, 1884, with the six boilers at the paper-works of Messrs. Zuber, Rieder and Co., on the Ile-Napoléon. The coal used was Sarrebruck von der Heyt III., composed of 57·2 per cent. of carbon, 5·8 per cent. of hydrogen, 8·2 per cent. of oxygen, 1·2 per cent. of nitrogen, 1·1 per cent. of sulphur, 3·3 per cent. of water, and 13·2 per cent. of ash. The coal yields 63·65 per cent. of coke.

The following Table contains in brief the comparative results of the trials:—

Conditions.	With Orvis. Continuous.		Without Orvis.		With Orvis. Intermittent.		Without Orvis.	
Date of trial . . .	Oct. 1	Oct. 2	Oct. 3	Oct. 4	Oct. 6	Oct. 7	Nov. 19	Nov. 20
Coal (dry) per sq. ft. or fire-grate . lbs.	9·18	10·35	9·30	10·25	12·54	12·30	6·72	7·13
Weight per charge ,,	26·4	24·9	26·8	24·4	25·7	27·1	19·9	21·1
Intervals, average min.	7.0	5.8	7.0	5.8	5.0	5.5	7.00	7.00
Pressure of steam atmo.	4·46	4·30	4·32	4·34	4·37	4·40	5·00	5·00
Water as from 32° F. evaporated per lb. of coal . . lbs.	5·99	5·43	5·82	6·23	5·54	5·49	5·80	5·52
Temperature of the escaping gases Fah.	473°	504°	489°	507°	531°	538°	437°	442°
Smoke duration:—	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	..	..
Black . . .	0 0	0 0	1 34	1 22	0 0	0 0	..	..
Brown . . .	0 0	0 0	1 25	0 56	0 0	0 0	..	..
Light . . .	1 52	2 0	2 39	2 37	1 20	1 28	..	..
Very clear . .	4 25	3 12	..	..	2 52	3 14	..	..
Analysis of escaping gases	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		
Carbonic acid .	8·7	8·7	6·3	6·3	8·0	8·0	..	..
Oxygen . . .	9·6	9·6	13·0	13·0	10·2	10·2	..	..
Carbonic oxide .	0·0	0·0	0·0	0·0	0·0	0·0	..	..

With respect to economy of fuel, it does not appear in this series of results that there is any advantage in the use of the Orvis system. Thus, to abstract the mean weights of water evaporated per lb. of coal, they are as follows:—

	Water per lb. of coal.
With the Orvis apparatus at work continuously . .	5·71 lbs.
Without the Orvis apparatus	6·03 ,,
With the Orvis intermittently	5·52 ,,
Without the Orvis apparatus	5·66 ,,

But evidently the Orvis apparatus was effective for the prevention of smoke, and it was effective also in improving combustion.

Subsequently, the more recent trials noticed in the first part of this abstract were instituted with a view to a final settlement of the comparative merits of the Orvis system.

D. K. C.

Experiments with Dupuis Boilers.

(Zeitschrift des Verbandes der Dampfkessel-Ueberwachungs-Vereine, 1886, p. 7.)

This is a report of experiments undertaken by the Silesian branch of the Society with two "Dupuis" boilers, on the 24th and 25th July of this year. The boilers were both alike, and built by the same firm, A. Leinveber and Co., of Gluwitz, in 1884; they were licensed to work with a pressure of 5 atmospheres (73·5 lbs. per square inch).

Each boiler consists of a nearly-horizontal cylindrical main-boiler 26 feet 7 inches long, and 4 feet 11 inches diameter, to which is connected by a horizontal tube 2 feet diameter, a vertical tubular boiler 10 feet 2 inches high, and 7 feet 2½ inches diameter, with one hundred and twelve vertical tubes, 3 inches diameter; below these, and parallel with the main-boiler, is a cylindrical "economiser," connected both to the main- and tubular-boilers by vertical tubes. The "economiser" has a length of 21 feet 8 inches, and a diameter of 2 feet 11½ inches.

The feed-water is introduced vertically through the main-boiler into the "economiser," descending through the tube connecting the latter to the former; from the "economiser" it circulates through the vertical boiler. The circulation is promoted by a special feed apparatus, by means of which the entering water draws down with it that in the main-boiler.

The grate is an ordinary one, 6 feet 3 inches long, by 4 feet 11 inches broad, with narrow firebars. The products of combustion pass first under the main-boiler, then downwards and along the "economiser," finally upwards through the tubes of the vertical boiler into the main-flue. The two upper boilers are suspended from wrought-iron brackets, while the economiser rests on cast-iron carriers.

The following are the most important dimensions and proportions of the boilers:—

Heating-surface in contact with water of one boiler	112	sq. metres	=	1,205·6		sq. feet.
Water space	23·63	cub. „	=	834·53	cub.	„
Steam „	9·22	„ „	=	325·62	„	„
Evaporative surface	16·17	sq. „	=	174·05	sq.	„
Total grate area	2·85	„ „	=	30·68	„	„
Free „ „	0·9	„ „	=	9·69	„	„
Ratio of grate area to heating surface			=	1 : 39·3		

The first experiment was made with both boilers, and lasted eleven hours; the fuel burned was small coal (*Staubkohle*).

The feed-water used was both measured and weighed; the coal

weighed independently by two observers. The following are some of the more important results obtained:—

Water evaporated per kilogram of coal from 55·44° Centigrade to steam at 3·87 atmospheres	6·22 kilos.
Do. do. deducting ashes	7·02 „
Water evaporated per square metre heating-surface per hour	15·14 „
„ „ („ „ foot per hour)	(3,102 lbs.)
Coal burned per square metre grate area per hour	95·7 kilos.
„ „ („ „ foot per hour)	(19·597 lbs.)
„ „ „ „ metre heating-surface per hour	2·44 kilos.
„ „ („ „ foot per hour)	(0·5 lb.)

An analysis of the coal used was made, and the heating power, calculated by Dulong's formula, found to be 6162 calories per kilogram (11,091·6 B.T.U. per pound).

The efficiency, as calculated from the preceding data, was found to be 60·25 per cent.

The second and third experiments were made with one boiler only, and with the object of ascertaining whether it were possible with this type of boiler to evaporate regularly 20 kilograms of water per square metre heating surface per hour (4·1 lbs. per square foot).

For the second experiment the same class of coal was used as for the first, but in the third, nut-coal (*Nuss-kohle*) was employed, for which the grate was reduced to ⅔ of its original length.

The experiments lasted 5¼ hours; the following are some of the more important results.

	Experiment II.	Experiment III.
	Centigrade.	Centigrade.
Temperature of feed-water before injector	20°	25·84°
„ „ after „	40·3°	46·58°
„ of gases at damper	326·76°	310·8°
„ of air in boiler-house	16°	16°
Steam pressure	4·285 atm. say 4·3 atm.	4·13 atm.

Experiment II.

Water evaporated per kilogram coal from 40·3° Centigrade to steam at 4·3 atmospheres = 154·3° Centigrade	6·06 kilos.
Do. do. deducting ashes	7·13 „
Water evaporated per square metre heating-surface per hour	21·6 „
„ „ („ „ foot per hour)	(4·428 lbs.)
Coal burned per square metre, grate area, per hour	140·35 kilos.
„ „ („ „ foot per hour)	(28·76 lbs.)
„ „ „ „ metre, heating-surface, per hour	3·57 kilos.
„ „ („ „ foot per hour)	(0·73 lb.)

Experiment III.

Water evaporated per kilogram coal from 46·58° Centigrade to steam at 4·13 atmospheres = 153·2° Centigrade	7·37 kilos.
Do. do. deducting ashes	7·73 „
Water evaporated per square metre, heating-surface, per hour	21·72 „
„ „ („ „ foot per hour)	(4·452 lbs.)
Coal burned per square metre, grate area, per hour	173·2 kilos.
„ „ („ „ foot per hour)	(35·49 lbs.)
„ „ „ „ metre, heating-surface, per hour	2·95 kilos.
„ „ („ „ foot per hour)	(0·604 lbs.)

	Experiment II.	Experiment III.
Efficiency	60 per cent.	69·7 per cent.
Loss through chimney . . .	1,777 Calories.	980 Calories.
„ by radiation and conduction	666 „	957 „

In the third experiment, it was found that the ratio of the quantity of air actually used to that required by theory was only 1·15—a very exceptional result.

G. R. B.

Performance of the Godillot Furnace for Steam-Boilers.

By H. Walther-Meunier.

(Bulletin de la Société industrielle de Mulhouse, March–April, 1886, p. 134.)

The Godillot furnace is designed for burning oak-chips (the humid refuse of tan-pits) which contain 62·3 per cent. of water. The boilers were two in number, semi-tubular, having each 1,076 square feet of heating surface. The following are the chief results of two days' trials :—

Date of trial	June 3, 1885	June 4, 1885.
Duration of trial	11 hours.	12 hours.
Weight of wet oak-chips consumed . . .	12,152 lbs.	31,960 lbs.
Loss of weight after sixty hours of drying .	62·3 per cent.	62·3 per cent.
Weight of water contained in the chips . .	7,570 lbs.	19,910 lbs.
Net weight of chips after sixty hours of drying	4,582 „	12,050 „
Weight of water fed to boiler	18,348 „	47,487 „
Temperature of feed-water	77·5° Fahr.	60·8° Fahr.
Working-pressure of steam	5·50 atmos.	3·82 atmos.
Water, as at 32° Fahrenheit, evaporated per lb. of fuel, wet	1·45 lbs.	1·45 lbs.
Water, as at 32° Fahrenheit, evaporated per lb. of fuel, dried	3·84 „	3·84 „
Wet fuel consumed per square foot of heating surface per hour	0·51 „	1·23 „
Steam generated per square foot of heating surface per hour	0·74 „	1·79 „
Temperature of the escaping burnt gases .	242·6° Fahr.	350·6° Fahr.

On the first day, the engine alone was driven, and required less steam than was used on the second day, when the machinery also was at work. The evaporative efficiencies were, it is noticeable, identical, being for both days, 1·45 lbs. of water per lb. of wet fuel, and 3·84 lbs. for dry fuel. This identity is explained by the enormous dead weight of water evaporated out of the fuel in each case.

D. K. C.

Experiments on Evaporation (of Steam-Boilers) at the Dessau Sugar-Refinery.

(Zeitschrift des Verbandes der Dampfkessel-Ueber-wachungs-Vereine, 1886, p. 47.)

The object of these experiments was to ascertain and compare the effect of various systems of firing. Nine boilers were made the subject of experiment; some of these were of the ordinary Lancashire type with the exception of the grates, others a combination of that type with the tubular boiler.

The systems of firing were as follow:—

I. Three boilers with ordinary step-grate.

II. One boiler with horizontal grate below step-grate.

III. Semi-gas-firing with central burner (Voelcker's patent).

IV. Ordinary step-grate with central burner with and without heated air-supply.

With two exceptions the fuel used was a clear brown coal from one mine (Grube Louise at Bitterfeld); in the two exceptional cases a different kind of brown coal from other mines was employed.

From each experiment the same quantity of coal 150 centners (7 tons 7·62 cwt.) was carefully weighed out and burned, except during one week when the quantity was 100 centners (4 tons 18·42 cwts.).

Three samples of the coal were taken for analysis on each day during the experiments, and from these an average sample for the whole time made up. The moisture was determined in each daily sample. Cinders and ashes were weighed daily and samples analyzed for carbon. The feedwater was heated and its temperature measured; it was supplied to the boiler by a steam-pump drawing from a tank; a certain quantity of water was carefully weighed and placed in the latter for each feed.

The steam generated was used for driving three steam-pumps, requiring 170 IHP.; care was taken to maintain the speed as constant as possible.

The boilers were carefully cleaned internally and externally, and put to work for thirty hours before the experiments commenced.

In the combined Lancashire and tubular boilers the products of combustion pass first through the internal flues, then upwards at the back end of the boiler, returning through the tubes to the front, and finally along the outside of both boilers and the steam-drum into the chimney.

The system of firing with Voelcker's central burner consists in supplying heated air through the internal flues to the fire gases.

In each flue is a cast-iron tube, resting on low brackets, and traversing the whole length; this tube terminates at the front end in a hollow cast-iron semicircular head, with slots in the circumference and a large orifice at the end, through which the air drawn from the boiler-house, on which the other end of the tube opens, after being heated in the latter, is supplied.

In the case of one boiler, in order to heat the air supplied to a still higher degree, it was first passed through a coil of tube placed in the main flue.

The most economical results were obtained by boilers with semi-gas-firing and central burner, the efficiency being as high as 80 per cent.

The pressure was in most cases nearly the same, about 5·5 atmospheres.

The chief dimensions of all the simple Lancashire boilers were similar, but the heating surface of the combined Lancashire and tubular boilers was much in excess of the former.

Very exhaustive tables of dimensions and results are given in the original, from which the following short summary of the most salient results has been compiled.

System of Boiler.	System of Firing.	Heating-Surface.	Grate-Area.	Water Evaporated from 0° to Steam of 100° C. Per lb. of Coal.	Water Evaporated from 0° to Steam of 100° C. Per Sq. Foot of Heating Surface.	Efficiency of Coal.
		Square Feet.	Square Feet.	lbs.	Lbs. per Hour.	Per Cent.
Ordinary Lancashire	Step-grate . .	805·82	35·52	2·10	4·908	65·25
Combined Lancashire and tubular . .	Horizontal below step-grate	2,282·0	57·26	2·72	2·526	84·63
Do. do.	Step-grate . .	2,282·0	55·54	2·38	2·318	74·06
Ordinary Lancashire	Step-grate with central burner	843·70	36·38	2·42	4·633	75·30
" "	Step-grate with central burner air-supply heated in main flue . . .	843·70	36·38	2·57	4·342	79·81
" "	Step-grate . .	843·70	36·38	2·21	4·526	68·58
" "	Semi-gas-firing with central burner . .	871·90	44·67	2·68	4·449	78·52
" "	Step-grate . .	871·90	45·21	2·18	4·664	68·20
" "	" " . .	871·90	45·21	2·23	5·520	69·40

G. R. B.

Performance of Mulhausen Waterworks Pumping Steam-Engines.

By H. Walther-Meunier.

(Bulletin de la Société industrielle de Mulhouse, 1886, p. 133.)

The pumping steam-engines of the low-service waterworks of Mulhausen, constructed by the Alsatian Society, were tested for economy and performance by Mr. Walther-Meunier, in 1885. The engines are horizontal, compound receiver condensing engines.

The pumps are connected directly to the piston-rod of each cylinder. The cylinders are 18·7 inches and 26·6 inches in diameter, with a stroke of 1 metre, or 39·37 inches. The pumps are 9½ inches in diameter, with 39·37 inches of stroke.

The chief results of the performance of No. 1 pumping-engine in ordinary working condition, were as follows:—

Working-pressure in the boiler 6½ atmospheres, or about 97 lbs. per square inch absolute; number of revolutions per minute, 27·42; speed of piston, 180 feet per minute; indicator-power, 65·1 HP.; steam consumed per IHP. per hour, 16·38 lbs.; water delivered by the pumps per minute, 1,001,220 gallons, raised to a height of 183·44 feet; power developed in useful work done, 55·64 HP.; steam consumed per HP. of work done, 19·196 lbs.; efficiency, or ratio of the useful work to the indicated power, 85·3 per cent.

In a preliminary trial, indicator-diagrams were taken from the pumps at the same time as those from the engine; and the results showed the efficiency of the engine 89·6 per cent.; and that of the pumps, 95·2 per cent.

D. K. C.

Excavator of Jacquelin and Chèvre, modified by Bourdon.

By G. Richou.

(Le Génie Civil, vol. ix. 1886, p. 107, 4 woodcuts.)

The excavator designed by Messrs. Jacquelin and Chèvre for excavating deep cuttings from the bottom, has been described in detail in a previous article;[1] but its working at the Panama Canal showed that certain modifications were desirable to enable it to work well in the enlargement of cuttings. The engine and boiler, placed on a truck on the prolongation of the line of way, formed a suitable counterpoise when the chain of buckets worked in opening out a cutting; but the stability of the excavator was considerably reduced, by the shortening of the lever arm of the counterpoise, when the buckets worked sideways in enlargements. Also a special motor for the progression of the excavator, which is intermittent, was unnecessary, and could be effected by a hand-winch. The engine and its boiler are now placed on the same revolving platform as the beam supporting the chain of buckets, so that the chain of buckets is fully counterpoised in any position; the length of the truck is reduced to a minimum, and the motor for progression is dispensed with. The working of the drum by bands, to avoid breakages from sudden impediments in working, the discharge of the material in the central axis of the revolving frame, and the special arrangements for increasing the efficiency of the buckets,

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[1] Le Génie Civil, vol. v. p. 357.

already described,[1] are retained. The modified excavator only weighs 30 tons, and consists of light parts easily transported. The materials are discharged into wagons, either by means of a shoot, or by a transporter with a travelling-band. In the first case, a platform on wheels, with two turntables on it, follows the excavator; a space is left for a wagon to go under the shoot on a cross-road between the turntables; and the up and down lines for the empty and full wagons are connected with the turntables by little inclined planes. Whilst the central wagon under the shoot is being filled, the full wagon on the turntable of the down line is pushed down the inclined plane, and by means of a cable passing round pulleys, draws up the next empty wagon, on the up line, on to the other turntable, ready to take its place under the shoot. The transporter rests at one extremity on the pivot of the excavator, and near the other end on a wide support, so that it can be pulled over either line of way for filling the wagons underneath. Both systems work equally well; but the first, owing to its simplicity and moderate price, seems a most useful accessory of the excavator.

L. V. H.

On Abrasion by Grinding. By A. Martens.

(Mittheilungen aus der mechanisch-technischen Versuchsanstalt, Berlin, 1886, p. 3.)

The importance of determining the resistance to mechanical wear or abrasion of materials used in the technical arts is generally admitted; the methods usually applied for testing this have been grinding and boring, but in most cases they have proved unsatisfactory.

A great many circumstances have to be taken into account in making experiments on abrasion, and according to the conditions under which they are carried out the relative results may be very different.

In most cases in which inquiries were received by the Experimental Institute for tests of this kind, they led to no result, as success could not be guaranteed beforehand.

In one case, however, some samples of linoleum were submitted for testing by a firm, and the experiments successfully carried out.

A grindstone of 347 millimetres (13·66 inches) was fixed in a double-geared lathe, and above it a cast-iron stamp connected with a parallel motion, so arranged that it could be brought nearer to or further from the stone at pleasure; on the top of this stamp was a cylindrical wrought-iron rod, over which lead weights, with a circular hole in the centre, could be placed, to exert pressure on the stamp. The surface at the lower end of the stamp was curved to the radius of the grindstone, and had an area of $5 \times 5 =$

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[1] Minutes of Proceedings Inst. C.E. vol. lxxx. p. 399.

25 square centimetres (3·875 square inches). The piece of linoleum to be tested was attached to this surface with shellac, and would be pressed against the grindstone by the weight of the stamp, plus half that of the parallel motion, its whole area being in contact with the stone. The number of revolutions were recorded by a counter in connection with the lathe.

It was found, by preliminary experiments, that with continued grinding the stone lost its sharpness, and to remedy this fine sand was constantly sprinkled over the surface, and had the effect of keeping the latter in good condition. A simple arrangement for regulating the supply of sand in the first instance, and afterwards ensuring its constancy, was made. Thirty drops of water per minute were allowed to fall on the stone.

The measurement of the amount of abrasion taking place was effected every ten minutes, by means of a gauge furnished with micrometer adjustment; the distance measured was that between the top of the flanges holding the grindstone on either side, and a horizontal steel bar attached to the stamp. The details of results are given in a tabular form. The standard of comparison for the various samples tested was the amount of abrasion for 100 metres traversed by the surface of the stone.

G. R. B.

A New Tubular Compass. By — Hildebrand.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxxiv. 1886, pp. 83–86.)

For extensive mine surveys, the magnetic needle is usually employed in conjunction with the theodolite. For this purpose, in theodolites of German make, a rectangular box-compass is placed between the telescope supports, and is read by means of a magnifying-glass. Good illumination of this compass is, however, hardly possible; the reading is difficult, and the results are not sufficiently accurate. At the same time, the introduction of the compass renders the theodolite more complicated, and its manipulation more difficult. In order to obviate these difficulties various methods have been adopted. These may be divided into two classes. In the first, the needle is suspended by means of a silk fibre; and with instruments of this kind, when firmly fixed, excellent results are obtained; but, as portable accessories to the theodolite, their manipulation requires great skill, and they have not come into general use. The second group includes compasses of various kinds, in which the needle is supported on a steel point. Of these, the tubular compass is the best. This consists of a tubular case, the north end of which is closed with a ground glass, on which a fine scale is marked. By means of a lens at the south end of the tube, this scale appears slightly magnified, and in front of this swings the north point of the needle, which is bent upwards so that it can be easily read with precision in the mine. The compass can easily be adapted to the theodolite, since it is not necessary to

read it from above, but by looking through it in the same way as an ordinary telescope. Unfortunately, for exact measurements it cannot be employed, as only one end of the needle is seen.

This disadvantage has induced the Author to construct a new form of tubular compass. In this, both ends of the needle are seen at once, magnified ten times; the graduation also appearing magnified to the same degree. The compass can easily be read to a single minute, both by daylight and in the mine, the light of a candle at a distance of a yard being sufficient underground. The tube is rectangular, and in it a magnetic needle 4·32 inches long swings on a steel point. Close by the south end of the needle is a glass micrometer, and in front of this is a micrometer eye-piece magnifying ten times. Between the south end and the centre of the needle is a small telescope objective. By means of the eye-piece, the glass micrometer and the south end of the needle are seen magnified ten times; the magnified inverted optical image of the north end, formed by the objective, being also visible. In other words, by means of the eye-piece both the north and south ends of the needle are seen passing before the glass micrometer. The latter is divided into tenths of a millimetre; one division as seen through the eye-pieces consequently appearing equal to one millimetre. The middle line of the scale—the zero line—is lengthened in both directions. When the needle is properly adjusted, the image of the south end and of the inverted north end will appear on this line. But if the needle gets out of adjustment, its centre and the north and south points are no longer in the same plane, and the two ends will not coincide with the zero line. In order to eliminate this error, the compass must be placed in such a way that the north end and the south end are at the same distance from the zero line. The north end of the compass-case is protected from dust by a glass-plate, in front of which is hinged a plate of ground glass, by means of which the artificial illumination is assisted.

If the ground-glass plate and the glass protecting the north end of the case are replaced by a tube with an objective at the end, a terrestrial telescope is obtained, in which the optical part of the tubular compass forms the eye-piece, and its glass micrometer represents the crossed wires. If a telescope of this kind is mounted on a vertical axis, and a graduated horizontal staff fixed at a suitable distance along the line of sight, the instrument may be employed for observing the diurnal declination.

B. H. B.

Signals for Mine-Surveys. By J. Gretzmacher.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxxiv. 1886, p. 239.)

In mine-surveys it is not advisable to employ candle-flames as angular objects for lines that are less than 30 to 40 fathoms in length. It is best in such a case to sight a plumb-line suspended

from the angular point. This will appear as a black line on a light ground, if a clean sheet of paper soaked in oil is held behind it, and illuminated by a candle. It is found, however, that exact pointing cannot be effected by this method in the case of very short lines. Both the vertical wire of the telescope, and the plumb-line appearing as black lines, it is impossible to halve the plumb-line with precision. The Author, therefore, advocates, for surveys where great accuracy is required, the employment, as signal, of a plate of sheet-iron suspended from the plumb-line. In this plate, three circular or square holes are bored in the longitudinal axis of the plumb-line. The plate is about 8 inches in diameter, and the holes 0·4 inch, 0·4 inch, and 0·07 inch in diameter; one of the larger apertures being covered with a piece of ground-glass. For very short distances, the flame of an ordinary mining lamp is held behind the small aperture; for greater distances the larger aperture covered with ground-glass is used; while for still greater distances the ground-glass is dispensed with.

B. H. B.

Ore-Dressing by means of an Air-Blast. By E. W. Neubert.

(Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, 1886, p. 71.)

In the methods of dry concentration hitherto employed, the ore to be treated has been allowed to fall through a free space, into which compressed air is passed. This separates the various constituents of the ore, according to their specific gravity. In the recent experiments carried out by the Author at the Himmelsfürst mine, Freiberg, a new method has been adopted. The ore is spread over a moving endless band, and air-currents passed over it. The endless band is of india-rubber; it is 1 foot 6 inches broad, and moves at a velocity of 4·32 to 4·72 inches per second. On one of the long sides of the band is the blast-main, with five twyers, through which the blast is directed over the ore spread on the band. The orifices of the twyers are 9·84 inches long. The ore passes from a hopper through distributing-rolls on to the endless band. In order to equally distribute the mass, four leather straps, 0·2 inch wide, are stretched across the band between the twyers. The surface of the band, constantly subjected to the blast, is 6 feet 2 inches long. Opposite the twyers, on the other long side of the band, are five bunkers, into which the products are blown. The blast is supplied from a fan, with 13·39-inch vane, worked by a small steam-engine, and making 1,250 to 1,300 revolutions per minute.

The products vary according to the nature of the raw ore. With masses of little value, containing a large quantity of gneiss, the first and second twyers give deads, the third, fourth, and fifth intermediate products, while the material remaining on the endless band, and passing into a bunker at the end, may be good ore. The intermediate products are worked again. The process is

exactly similar to washing on inclined planes, complex ores having to be treated repeatedly, in order to separate the different constituents. For large establishments it would be advisable to employ two or three concentrators, with five twyers each, rather than a single concentrator with ten to fifteen twyers. It is important that the material to be treated shall be perfectly dry, well sized, and free from dust.

The Author gives the results of twenty experiments made with various ores, analyses being given of the original ore, of the concentrated products, and of the deads. In one experiment, coarse ores of 0·06 to 0·1 inch grain was employed. This contained 0·1 per cent. of silver, 1 per cent. of lead, and 6 per cent. of zinc. The results were satisfactory, as showing that poor ores can be treated by the dry process. The production was 12·39 per cent. of concentrated ore, containing 0·032 per cent. of silver, 5 per cent. of lead, 28·4 per cent. of sulphur, and 10 per cent. of zinc. The products from the first two twyers, the deads, were completely free from lead; the intermediate product was also worthless. In another experiment, ore of 0·04 to 0·06 inch grain, containing 0·012 per cent. of silver, 0·5 per cent. of lead, 7·4 per cent. of sulphur, and 6 per cent. of zinc, gave 10·35 per cent. of concentrated ore, with 0·032 per cent. of silver, 7 per cent. of lead, 23·8 per cent. of sulphur, and 11 per cent. of zinc. This yield is 2 per cent. greater than that from the percussion table. The experiments show that the method of air-separation may be employed with advantage for the concentration of ores. Galena especially concentrates well, and can be separated to a minimum from the other constituents of the raw mass. Iron pyrites and blende cannot be separated by this method. The preliminary work presents several difficulties. Comminution by dry stamping is entirely out of the question, from the fact that 50 to 60 per cent. of the mass is reduced to a powder of less than 0·08-inch grain, which could not be separated by the blast. The cost of the method described is higher than with wet stamping and washing, but not so high as with breaking, and crushing in rolls. Crushed ore with 5 per cent. of lead may, consequently, be treated with advantage by this method.

B. H. B.

Calorimetric Study of Iron at High Temperatures.

By — Pionchon.

(Comptes rendus de l'Académie des Sciences, vol. cii. 1886, p. 1454.)

The Author's experiments were made upon almost pure iron, with only the slightest traces of carbon and silicon. From 0° to 660° Centigrade, the quantity of heat required to raise its temperature is given by the formula—

$$0{\cdot}11012\,t + 0{\cdot}0000253\,t^2 + 0{\cdot}00000005466664\,t^3;$$

between 660° and 723°, the increase in the quantity of heat required is much more rapid—

$$0 \cdot 57803\, t - 0 \cdot 001435987\, t^2 + 0 \cdot 000001195\, t^3 ;$$

whilst from 723° to 1000°, the quantity of heat is represented by the linear equation,

$$0 \cdot 218\, t - 39.$$

It may be remarked that the specific heat of iron (0·218) in the last interval of temperatures, is double of what it is about 0°.

Measures made with copper between 660° and 723°, showed no change similar to that observed with iron. To discover whether it effected the substance, or only the structure of the metal, experiments were made on spongy iron, reduced from pure sesquioxide of iron by hydrogen, the results agreeing perfectly with those obtained previously. The fact of a change in the state of iron occurring at about the temperature of 700° being thus established, the Author proposes to extend his researches on the influence which this change of state may have on the different properties of this metal, and on steel. Mr. Becquerel remarked that iron about the temperature of 600°, presented another very remarkable change in its physical properties, namely, the diminution in the attractive influence upon it of magnets. Nickel and cobalt, at 400° and at white-heat respectively, are similarly influenced, and it would be interesting, he thought, to discover whether their capacity for heat changed at these temperatures in a manner analogous to that of iron.

E. F. B.

On the Blowing of Small Bessemer Charges.

By Prof. T. M. Drown.

(Proceedings of Society of Arts of Massachusetts Institution of Technology, 1885–6, p. 141.)

The Little Bessemer process was first tried at Avesta, in Sweden, some eight or nine years ago, with the design of making a sort of iron sponge to use in the Martin process. The high temperature developed, and the fluid character of the final product were a surprise to the projectors of the process, which proved so satisfactory that the intention of putting up a Martin plant was abandoned.

The process was first described by Professor Josef von Ehrenwerth,[1] of Leoben, in Austria, who visited the Avesta works in 1884. There were then two converters, movable on their axes by hand-power. Their height is from 51 to 54 inches, and the diameter

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[1] Minutes of Proceedings Inst. C.E., vol. lxxix. p. 434.

39 inches. The bottom, which is secured by a screw, is made of one piece, containing about 90 twyers, 0·12 to 0·13 inch in diameter, distributed in a circle of only eight inches, and inclined at an angle of 45° to 50°.

The moulds are filled direct from the converters, no ladle being used, and steel and cinder are poured out together. The blast is supplied by the same engines that supply the blast-furnace, with a pressure of 15 lbs. to the square inch. The charge of from 365 to 1,700 lbs.—on an average, say about 1,000 lbs.—is taken direct from the blast-furnace, and forty-five to fifty charges are blown in each converter in twenty-four hours, including the necessary changes of converters and bottoms. The blows seen by Ehrenwerth lasted 13½ and 9 minutes respectively. The course of the blow is essentially the same as in the regular Bessemer process, except that it is completed with low pressure of blast.

Although cold charges are often blown, and notwithstanding the small amount of metal in the vessel, the steel is thoroughly and normally hot at the finish. At the end of the blow, 8 per cent. of ferro-manganese is added in small pieces, cold (the vessel being on its side), the mixture is rabbled with a stick of wood, allowed to stand quietly for some minutes, and then slowly poured into the moulds without any attempt to hold back the cinder.

As the result of a year's working (1879), there was 87·4 per cent. of ingots produced to 12·6 per cent. loss on the pig-iron used, and since then a better record has been shown. There is no loss by skulls in ladles, and as the slag is poured with the steel into the moulds, there is less loss at the top of the ingot. (In more recent working the greater part of the cinder is retained by inserting a brick in the mouth of the converter.)

The product is exclusively ingot iron, with carbon from 0·2 to 0·55 per cent., and according to Ehrenwerth, it is characterized by its excellent quality, by its uniformity in strength, and above all, by its fibrous, or rather silky, texture, in which respects it surpasses the best varieties of refined or puddled iron.

Analyses of the pig-iron, and of the final product, give the following results:—

	Pig Iron.		Bessemer Iron.	
Carbon	?	?	0·20	0·25
Silicon	1·40	1·46	0·05	0·11
Manganese	0·63	0·47	0·31	0·31
Phosphorus	0·043	0·047	0·051	0·05
Sulphur	0·01	0·00	0·00	0·00
Slag	..	..	0·05	0·5

Ehrenwerth considers this product to be distinguished chemically by the presence of slag and the absence of sulphur. The amount of silicon is higher than might be expected, and some of it is probably due to intermingled slag.

The physical properties of the metal are—tensile strength per square inch, 50,000 to 53,000 lbs.; elongation in eight inches, 25 to 30 per cent.; contraction of area, 60 to 68 per cent.

According to Ehrenwerth, the essential characteristics of this process are—

1. Small but numerous twyers, in an inclined position, giving a better distribution of blast, and ensuring its complete utilization.
2. Pouring from the *hot* retort.
3. In general, a better heating of the retort, particularly in its upper part.
4. High gas-pressure in the retort, owing to its narrow neck.

Shortly after Ehrenwerth's description of the Avesta process, experiments in blowing small charges were made at the Bessemer works at Prevali, in Austria, under the direction of W. Hupfeld. The first converter was constructed inside a regular Bessemer vessel, and took a charge of from 1,300 to 1,400 lbs. The softest metal made in this experimental converter contained 0·14 per cent. of silicon, and 0·12 per cent. of carbon, and the hardest 0·075 per cent. of silicon and 0·71 of carbon. Here again there is a probable error in the silicon determinations owing to intermingled slag.

In a second series of experiments, with a new converter, near the blast furnace, the small charge, 1,400 to 1,600 lbs., was taken from the ladle which supplied the large converters, and thus a large and a small charge were blown at the same time from identically the same iron. This gave an opportunity for a direct comparison of the products, and it was found that the metal made in the small converter was always better than that blown in the large converter. Large quantities of the product of the small vessel were made into wire, sheets, and boiler-plate. It was decidedly tougher than puddled iron, while its weldability was perfectly satisfactory.

Of sixty consecutive charges blown for soft metal in this converter, the average amount of silicon was 0·0281 per cent.; of carbon, 0·1166 per cent. The lowest silicon was 0·014, and the carbon varied from 0·08 to 0·16 per cent. Of the corresponding charges in the large converter, when the same degree of softness was aimed at, the average was 0·055 per cent. of silicon, and 0·126 of carbon. The extremes of silicon in the metal made in the large converters are, unfortunately, not given by Hupfeld, who shows from these comparative experiments that when in the Little Bessemer process the carbon is brought down to the same point as in the regular process, the silicon is more completely eliminated.

In the Clapp-Griffith process, in which also small charges are treated, the converter is of the original Swedish pattern, its peculiar feature being a slag tap-hole, at such a height in relation to the metal under treatment, that when the cinder is formed and boils up as the blow progresses, it can be run off and thus be removed from contact with the iron, and will also be out of the way when the decarbonized metal is tapped into the casting-ladle

and the manganiferous alloy added. The twyers are situated around the body of the vessel, and enter the interior at some distance above the bottom. At the completion of the operation the metal is tapped into a ladle, and is there mixed with the ferro-manganese, and then cast into ingots in the usual way. A slow pressure of blast, from 5 to 8 lbs., is used.

The product of the Clapp-Griffith converter is also low in silicon, which seldom exceeds 0·02 per cent., and it is claimed that this low proportion is a necessary result of this system of blowing.

Unfortunately the records of analyses of Clapp-Griffith metal low in phosphorus, are too few in number to afford a trustworthy comparison of its physical properties with those of the metal made in the small converters at Avesta and Prevali.

While the high quality of the products of small converters, especially as regards softness and ductility, appears to be generally conceded by competent judges, the reason for its excellence is not so apparent. Ehrenwerth has no explanation to give of the superior quality of the Avesta metal other than the fact that pig-iron low in silicon is used, and that the wind is more thoroughly mixed with the iron owing to the large number of very small twyers. Hupfeld's view is, that it is due to the more complete elimination of silicon in the Little Bessemer, and says that the only respect in which the soft Bessemer metal ordinarily made in Austria is inferior to basic or Martin steel, is the somewhat higher percentage of silicon, namely, 0·035 to 0·06 per cent. As has been already seen, none of the metal from the small converter at Prevali contained more than 0·05 per cent. of silicon, and in two-thirds of it the silicon was not more than 0·03 per cent., while it is generally admitted that the Clapp-Griffith metal is yet lower in silicon.

What, then, are the essentially different conditions in the small converter, so that it necessarily produces metal lower in silicon? It seems to be generally admitted that a very high temperature in the Bessemer converter is unfavourable for the complete elimination of silicon, and it is not improbable that silicon, which has already been oxidized, may be again reduced and united with the iron. But if the simple solution of the success of the Little Bessemer is, as Hupfeld suggests, that the charges blow cold, it would not be a difficult condition to imitate in the larger vessel. The following interesting particulars, furnished by Mr. P. W. Moen, of Worcester, Mass., seem to confirm this view:—

"Some time ago, at the Domnarfvet Works, Sweden, in attempting to turn down their converter, the turning arrangement gave out, and the converter was held suspended in such a position that it was necessary to keep on the blast in order to prevent the metal from flowing back into the twyer holes. It was naturally thought that the blow would be a loss, but very much to the surprise of the engineers it was discovered that the iron was very soft, unusually so, and that, contrary to the general rule with them, it was quite free from red-shortness, due to the presence of oxide of

iron. The after-blow, if it may be so called, was made with a portion of the tuyeres (not all) above the surface of the bath, and undoubtedly caused a motion of rotation in the bath."

This practice was continued for above a year, whenever unusually soft iron was required, but was ultimately abandoned, partly on account of the greater waste due to the excessive oxidation of the iron. This, it may be remarked, would tend to make the cinder more basic and abundant, and thus to retain all the oxidized silicon.

The conclusion seems inevitable, that in the large converter, ingot-iron can be made as soft and ductile in every respect as in the small converter, by conforming to the same conditions; but that in the blowing of small charges the conditions for the production of soft metal are inherent, so that the Little Bessemer has the merit of producing extra soft iron, because it cannot help it.

The pig-irons thus far used in Europe in the Little Bessemer have been exclusively those used in the regular process. But in the Clapp-Griffith converter, in America, pig-irons high in phosphorus have been experimented on, and have given a metal of unexpected ductility, and it is consequently claimed that phosphoric irons can be successfully treated by that process.

W. S. H.

Gold-Mining on the Saskatchewan. By Charles Levey.

(Proceedings of the Canadian Institute, 1886, p. 267.)

The gold-fields referred to are at and near Edmonton, on the North Saskatchewan river, N.W.T. Canada. The deposit, through which the present river cuts, is said to extend some 60 miles east and west. The northern and southern limits are not known. The thickness of the deposit is partly seen by the height of the river banks, which, at the point referred to, are at least 200 feet high. At the highest points, on some of these banks, gold can be washed out, but the quantity per cubic yard of dirt increases as the present water-level is approached. On the gravel bars the yield by hand-working is about \$1·60 per cubic yard. The gold is in the shape of very fine dust and minute nuggets. The largest of these nuggets is not larger than the smallest mustard seed. The gold is separated from the dirt by hand. A dump-box is filled with gravel, after which water is dashed upon it by the aid of a long-handled dipper. The coarse parts fall on either side of a double-inclined grate, while the finer parts fall through the grates on to blankets in a box; all but the black sand and the gold are discharged. The latter adheres to the blankets. The dump-box is filled and emptied repeatedly for, say, ten hours, after which the blanket is washed in an ordinary tub, to the bottom of which the gold and black sand fall. The water is next poured off,

and two or three charges of fresh water are poured into and out of the tub, in order to further cleanse the gold and black sand. When these are sufficiently clean, they are removed from the tub to the gold-pan. This is done by tipping the tub over the pan, and then by dashing water from the pan into the tub. The gold cannot be successfully removed from the tub in any other way. The pan is now held under water, and shaken until the mass it contains is much reduced in bulk by the separation of the lighter portions of the sand. Some quicksilver is poured in, together with clean water, and the pan is shaken until the quicksilver has taken up all the gold. It is then again placed under water, and violently shaken, to remove all the black sand. The remaining contents are then poured into a washleather, which has been previously wetted and stretched. The edges of the leather are secured in the right hand, when the centre of it assumes the shape of a pounce. The neck of this is wrung until all the free quicksilver is squeezed through the pores of the leather, and falls in fine beads into the pan placed for its reception. When opened, the bag is found to contain a ball of amalgam, of silver colour, and of about the consistency of putty. This is moulded in the fingers to the required shape, and then placed upon an iron shovel. Heat is applied beneath the shovel to drive off the quicksilver that could not be removed by pressure. After a sufficient application of heat, the button of amalgam assumes a gold colour, and is allowed to cool. This is the gold amalgam of commerce. The rest of the Paper is descriptive of the machine methods of recovering the gold.

The Author remarks that handwork has been going on for nine years, and machinery work five years; the first was not commonly satisfactory, and the other produced about \$6 per day; that the tract was 200 miles north of Calgary, and extended 50 miles; that the yield per pan was about 2 cents; that the sand contained magnetic iron and a little platinum; that there were from fifteen hundred to two thousand settlers; that there were large boulders of gneiss and granite, which, he thought, came from the Laurentian to the north-east, and he thought hydraulic mining would pay after a very large expenditure.

The Desilverization of Lead by means of Zinc at Freiberg.

By C. A. Plattner.

(Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, 1886, p. 133.)

The Parkes process has recently been introduced at the Royal Muldener works at Freiberg, in conjunction with the Pattinson process. The latter cannot be entirely dispensed with at these works, on account of the bismuth in the argentiferous lead. The

combined Pattinson-Parkes plant is as follows:—For the Pattinson process there are two batteries of nine cast-iron pots, 5 feet 8 inches in diameter, 2 feet 11 inches deep, and with a capacity of 15 tons. For the Parkes process there are two cast-iron desilverizing pots, 6 feet 5 inches in diameter, 3 feet 3 inches deep, and with a capacity of 20 tons; three cast-iron hemispherical liquation pots, 1 foot 9 inches in diameter; one refining furnace, with a fire-brick bottom 9 feet 10 inches long, 6 feet 6 inches broad, and 1 foot 5 inches deep, for separating the zinc from the poor lead; and one cast-iron tapping-pot, 5 feet 14 inches in diameter and 3 feet 3 inches deep, for receiving the lead from which the silver has been removed. The lead containing 0·1 per cent. of silver, to be treated by the Parkes process, is removed from the last Pattinson pot by means of Rösing's steam lead-pump.[1] Lastly, there are two furnaces for distilling the rich argentiferous crusts obtained in the Parkes process. These are air-furnaces, each containing a plumbago crucible and an iron condenser.

The mode of procedure is as follows:—The refined argentiferous lead, with more than 0·1 per cent. of silver, is charged into the pot of the Pattinson battery, corresponding to its percentage of silver and is converted, by the usual method of thirds, into a rich lead with 2 per cent., and a poor lead with 0·1 per cent., of silver. The rich lead is cupelled, and the poor argentiferous lead is treated by the Parkes process. The time occupied by the desilverization is not more than twenty hours, five hours being required for the melting of the argentiferous lead and collection of the argentiferous zinc crusts, and five hours for each period of desilverization, that is, from one addition of zinc to the next. The lead from the Pattinson process, with 0·1 per cent. of silver, requires at most three additions of zinc. Each charge of 20 tons of lead, with 0·1 per cent. of silver, requires 473 lbs. of zinc, 220 lbs. for the first addition, 165 lbs. for the second, and 88 lbs. for the third. The original proportion of 0·1 per cent. of silver, and 0·004 per cent. of gold, in the argentiferous lead, is reduced, after the first addition of zinc, to 0·025 per cent. of silver and a trace of gold; after the second addition, to 0·002 per cent., and after the third addition to 0·0007 per cent. of silver, and no gold.

The following figures, giving the results obtained by treating Freiberg leads with the maximum (0·8) and minimum (0·4) percentage of auriferous silver, show how the combined Pattinson-Parkes process compares with the simple Pattinson process hitherto in use.

1. Lead containing 0·84 per cent. of auriferous silver gave, with the Pattinson process in sixteen pots: rich lead, 41 per cent., with 2 per cent. of auriferous silver; commercial lead, 49 per cent., with 0·001 per cent. of silver; and lead, in intermediate products, 10 per cent., with 0·2 per cent. of silver. Of the gold and silver

[1] Minutes of Proceedings Inst. C.E. vol. lxxxiv. p. 512.

present, there was collected 97·6 per cent. in the rich lead, 0·1 per cent. in the commercial lead, and 2·3 in the intermediate products. The cost was 7·53*d*. per cwt. of argentiferous lead. With the combined Pattinson-Parkes process, with nine pots, there was obtained: rich lead, 38·9 per cent., with 2·11 per cent. of auriferous silver; commercial lead, 52·5 per cent., with 0·001 per cent. of silver; lead, in intermediate products, 8·6 per cent., with 0·18 per cent. of silver. Of the gold and silver present, there was collected 99·1 per cent. in the rich lead, 0·1 per cent. in the commercial lead, and 0·8 per cent. in the intermediate products. The cost was 6·34*d*. per cwt.

2. Lead, with 0·42 per cent. of auriferous silver, gave, with the Pattinson process in sixteen pots: rich lead, 20·5 per cent., with 2·0 per cent. of auriferous silver; commercial lead, 69·3 per cent., with 0·001 per cent. of silver; lead in intermediate products, 10·2 per cent., with 0·1 per cent. of silver. Of the gold and silver present, there was collected: 97·6 per cent. in the rich lead, 0·1 per cent. in the commercial lead, and 2·3 per cent. in the intermediate products. The cost was 7·04*d*. per cwt. of argentiferous lead. With the combined Pattinson-Parkes process, with only eight Pattinson pots, there was obtained: rich lead, 17·16 per cent., with 2·39 per cent. of auriferous silver; commercial lead, 73·52 per cent., with 0·001 per cent. of silver; lead in intermediate products, 9·32 per cent., with 0·08 per cent. of silver. Of the gold and silver present there was collected 98 per cent. in the rich lead, 0·1 per cent. in the commercial lead, and 1·9 per cent. in the intermediate products. The cost was 5·53*d*. per cwt. of argentiferous lead.

In comparison with the simple Pattinson process, the combined process in the above two cases gave:—

	1.	2.		
Rich lead	2·1	3·34	per cent.	less.
Commercial lead	3·5	4·22	„	more.
Intermediate products	1·4	0·88	„	less.
Cost	18·0	21·45	„	„

Instead of the twenty-seven workmen formerly required for the sixteen Pattinson pots, only twenty-two are now required for the desilverization and distillation, and the yield of rich and commercial lead per working day has increased 18·3 per cent.

B. H. B.

Frictional Resistance of Steel Hoops shrunk on Steel Tubes.

By F. H. Parker.

(Proceedings of the American Society of Civil Engineers, 1886, p. 45.)

The test for frictional resistance to longitudinal removal of steel hoops which were shrunk on steel tubes, was conducted by Major F. H. Parker, of the United States Ordnance Department, at

Watertown Arsenal, Mass. The specimens were prepared at West Point foundry. Two pieces of tube, 8 inches in bore, 15¾ inches in external diameter, and 5½ inches and 6½ inches in length respectively, had two hoops shrunk upon them respectively 3 inches and 4 inches wide, and 2⅛ inches thick. The temperature of the 3-inch hoop when taken from the furnace to "assemble," was estimated at 470° Fahrenheit; and that of the 4-inch hoop at 515° Fahrenheit. The unhooping, or forcing off of the hoop from each tube, was done in the direction of their axes, in the United States testing-machine, having a capacity of 800,000 lbs., at the arsenal. One end of the tube rested against the flat platform of the testing-machine, and a cast-iron ring was interposed between the opposite platform and the hoop. The external diameter of each hoop, and the internal diameter of each tube was measured before unhooping, and again after unhooping. They were as follows:—

EXTERNAL AVERAGE DIAMETER.

	Before unhooping.	After unhooping.	Restoration.
	Ins.	Ins.	Ins.
3-inch hoop . . .	20·0157	20·003825	0·011875
4-inch „ . . .	20·023625	20·012541	0·011084

INTERNAL AVERAGE DIAMETER.

	Before unhooping.	After unhooping.	Restoration.
	Ins.	Ins.	Ins.
Tube with 3-inch hoop	7·995958	7·998066	0·002108
„ „ 4 „ „	7·991441	7·994025	0·002584

INTERNAL DIAMETER OF HOOPS AFTER UNHOOPING.

3-inch hoop	15·745791 inches.
4 „ „	15·746092 „

EXTERNAL DIAMETERS OF TUBES AFTER UNHOOPING.

Tube with 3-inch hoop	15·762225 inches.
„ „ 4 „ „	15·762442 „

DIFFERENCE IN SHRINKAGE DIAMETERS AFTER UNHOOPING.

3-inch hoop and tube	0·016434 inches.
4 „ „ „	0·016350 „

The given values of the diameters are in each instance an average of four measurements at equal angles round the circle.

The hoops did not slip over the tubes with a smooth continuous movement, but with a series of sudden slips or throbs, during which there were fluctuations of the resistance and the load.

MAXIMUM FRICTIONAL RESISTANCE.

3-inch hoop and tube	265,800 lbs.
4 „ „ „	404,100 „

D. K. C.

Austrian Siege-Artillery.

(Revue d'Artillerie, 1885, p. 125.)

By the adoption, under an Imperial decree of April 1885 of a 5·9-inch mortar, the Austrian siege artillery has been completed. The series comprises guns of 4·7-inch and 5·9-inch bore, 7-inch short guns, and mortars of 3·5-inch, 5·9-inch, and 8·25-inch bore.

The 7-inch guns and 3·5-inch and 5·9-inch mortars are cast in one piece. The 8·25-inch mortar has a tube with trunnion hoop shrunk on. The 4·7 and 5·9-inch guns are strengthened by hoops of steel bronze over the chamber in front of the breech-block.

The rifling of the 3·5-inch mortar is of uniform twist, and the same projectiles are fired as for the 3·5-inch gun; they are fitted with four rings of copper wire. The remainder have progressive twist, which is carried into the conical shot-chamber, the depth of the rifling being 0·059 inch in the bore and 0·039 inch in the shot-chamber; this allows the shot to be centred at the moment of starting.

The breech is the wedge form, with copper Broadwell obturator. The breech-blocks carry a charging guide, but as the mortars require shorter blocks to enable them to pass between the sides of the carriages, the 3·5-inch is fitted with a fixed support, and the 5·9-inch and 8·25-inch with movable guides. Axial ignition, with obturating igniter, is used. The 4·7-inch, 5·9-inch, and 7-inch guns fire common and shrapnel shell, the 3·5-inch case-shot, and the 5·9-inch piercing and incendiary shells. The projectiles have two rings, one as a guide and one for driving.

The common shells are charged from the rear, and the opening is closed by a steel screw and lead ring. The shrapnel has lead balls, and is very little heavier than ordinary shell, being shorter.

The 5·9-inch incendiary shell is the same as the common shell, and uses the same fuze, but it has three holes in the head to allow the passage of flame. The piercing shell is of chilled iron, with a smaller chamber than the common shell. Only one band is used with this, the guiding being performed by a swelling near the head cast with the shell.

The 4·7-inch case-shot has zinc balls 1·1 inch diameter, weighing 3·3 ounces. For the 3·5-inch mortars, experiments are being made with shrapnel shell, having steel cylinders for the bodies, and an iron head screwed in. The 5·9-inch mortar and gun fire the same ammunition.

The 8·25-inch mortar fires shell like the 5·9-inch gun, but as the carriage does not allow firing except at angles above 45°, the time of flight is too great (with shrapnel) for the service time fuzes, and very satisfactory results, more accurate aim can be obtained with the 7-inch gun, firing at 20° with reduced charge. The carriages for the 1880 pattern guns are formed of two parallel

checks in plate, strengthened by angle-irons, and joined together by tie-pieces. The elevating apparatus consists of a double screw; in the 4·7-inch and 5·9-inch guns it is attached to the gun-hoop by a bolt, to prevent the muzzle dropping. The short 7-inch gun lies on the head of the internal screw, which is joined to the carriage by a forked link, otherwise the carriage is the same as that of the 5·9 and 7-inch guns. In these carriages the extremities of the axles are joined to the sides by thrust-rods; to facilitate loading, a folding foot-board is attached to the side of the carriage.

The 3·5 and 5·9-inch mortar carriages consist of two cheeks of plate, strengthened with angle-iron. The 8·25-inch carriage sides are double, and have a frame-piece riveted to the edges. A bracket on the left side receives the wedge when the breech is opened. The 3·5 and 5·9-inch mortars are elevated by toothed arcs, the 8·25-inch by a screw, allowing a range of fire from 45° to 65° only. A toothed arc on each side of the carriage changes the gun from firing to loading position.

For transport the mortars are furnished with axles and two wooden wheels; the 5·9 and 8·25-inch also have limbers. The 3·5-inch is moved like a wheel-barrow, and by means of a pair of shafts can be drawn by one man; for short distances in trenches it can be carried by three men. The 4·7, 5·9, and 7-inch gun-carriages, and the 5·9-inch mortars are fitted with hydraulic brakes. Specially adapted platforms are used for these gun-carriages and mortars.

The 4·7-inch gun is the light siege piece used in batteries. The 5·9-inch is used where direct but more powerful fire is required. The 7-inch gun is used for vertical fire. The 3·5-inch mortar is used in trenches for distances below 1,640 yards to reach behind earthworks. The 5·9-inch mortar is used for the same object at greater distances and for vertical fire.

The 8·25-inch mortar is available for the destruction of magazines, shelters, and bombardment up to 7,218 yards range.

Detailed tables of dimensions and weights of the mortars and their carriages and ammunition are given.

J. H. R. W.

Italian Field- and Siege-Artillery.

(Revue d'Artillerie, 1886, p. 337.)

The Italian Government having made a number of experiments to determine the construction of the various kinds of artillery required for the defence of the country, the 'Revue d'Artillerie' publishes the details of the mountain, field, siege guns, guns of position, and coast-defence guns which it has been decided to adopt.

The mountain-gun is a bronze breech-loader 2¾-inches bore

The carriage is of steel plate, on the Engelhart system, weighs 322 lbs., and with its fittings 336 lbs. Each wheel weighs 61¼ lbs., the diameter being 37·63 inches. The tests for reception consists of a series of five rounds with ordinary charges, two rounds at an angle of 5°, and three rounds at the maximum of 20°, the wheels being skidded on the ground. The ammunition for the mountain- and field-guns is not yet decided. The ammunition-boxes are made of wood, and weigh 29¾ lbs. Each contains four common shells, six shrapnel, and eleven cartridges. The supply of ammunition to each battery allows 234 rounds per gun. The gun-mule carries 313 lbs. including the weight of the saddle. The mule carrying the ammunition-boxes carries the greatest load, viz., 374¾ lbs.

The charge of the gun is 0·66 lb., the weight of projectile 9 lbs. 6 ozs. The initial velocity is 840 feet. The maximum range is 4,078 yards at 40° elevation. Shrapnel can be fired up to 2,187 yards. At 1,094 yards, the common shell penetrates 39·375 inches of earth, or a 9·75-inch brick wall. At 2,188 yards, the penetration is equal to 19·68 inches of earthen parapet, and at 437 yards it is equal to 15·75 inches of oak.

Field-Guns.—During the last two years, the three and a half field-batteries and the horse artillery have been fitted with metal carriages and limbers. All the steel-hooped guns of 3½-inch bore have been replaced by breech-loading bronze guns.

The 2¾-inch bronze breech-loading gun is of 1872 pattern, with a sight similar to that used in the mountain gun.

The battery of these guns consists of eight pieces, each gun having 70 shells, 66 shrapnel, and 6 case shot, or a total of 142 projectiles. The sides of several carriages showing cracks after firing about 400 rounds, and the wagons being almost always damaged by the tests for travelling, it was decided to make all the horse battery carriages of metal. The sides are of steel 0·24 inch thick; the edges are flanged inwards, parallel to the breech, and then converge towards the trail. They are stayed by steel transoms. The axle is of iron 3·3 inches in diameter, fastened to the sides by thrust-bars. The wheels are 41·1 inches in diameter; the tire is wider than the wheel to allow for dragging over soft ground. The carriage is fitted with both drag and screw-brakes, carries no seats, but two boxes are fixed on the axle, one for gun accessories, the other for two rounds of case shot. The limber is of plate and angle-iron, has a prismatic axle of iron, and wheels similar to the carriage. The ammunition-box carries 44 cartridges and 40 projectiles.

The limber of the ammunition-wagon is of iron and angle-iron, with the same axle and wheels as the carriage-limber. One large box for ammunition, and one small box with accessories for marching and camping, is fitted on each frame. The box carries sixty charges and fifty-five projectiles. Guard-irons and footboards are fitted to all the ammunition-boxes.

The two limbers, both for gun and wagon, are connected by

means of a spring coupling, which has been frequently objected to, it has been more particularly urged that the suspension spring would rapidly lose its elasticity, and that the trail would drop. Experiments made both with elastic and rigid couplings show that after a run of nearly 400 miles at various speeds, and over different ground, the springs lost none of their elasticity, and that the lowering of the trail was only from $2\frac{3}{4}$ to 4 inches, whereas with the rigid coupling it varied from 4 to 8 inches. This determined the adoption of the elastic spring which was strengthened a little. To provide against any lowering of the trail the futchel was thinned at its extremity, and fitted with an iron cap which terminated at the end with a nut in which a vertical screw worked, held by two plates fixed on the arms of the fork; by working the screw the futchel-end could be raised or lowered, at the same time causing the height of the end of the trail to be varied up to 19·68 inches.

The tests for reception consist of 1,000 rounds fired under various conditions.

The $3\frac{1}{2}$-inch breech-loading gun-carriage is of steel plate. 4000 rounds have been fired from it without any serious damage, and with slight modifications it has been adopted. The limbers and wagons have been considerably modified to enable the ammunition to be more readily drawn out in time of action. The weight of the trail on the ground has been reduced from 1 cwt. 2 qrs. $14\frac{3}{4}$ lbs. to 1 cwt. 1 qr. 25 lbs., thus making the training of the gun more easy. 130 projectiles, viz., 62 common shells, 62 shrapnel, and 6 case shot, are allotted to each gun in the battery.

The bodies of the shrapnel shell are made of steel, the heads of cast-iron; the results obtained have been much superior to those with iron, heavier projectiles, larger bursting-charges, and a greater number of bullets being obtained whilst the price is increased by about two shillings.

At 1,190 yards, $2\frac{3}{4}$-inch shell penetrate 11·8 inches of brickwork, 23·6 inches of wood, and 59 inches of earth. The $3\frac{1}{2}$-inch gun penetrates 19·6 inches of brickwork, 39·3 inches of wood, and 98·34 inches of earth.

Siege-Guns and Guns of Position.—These are of 4·7 inches and 5·9 inches calibre.

In 1883 some experiments were made with these guns with a uniform twist of rifling and parabolic rifling. The 5·9-inch gun with a final twist of 35 calibres was found to be no better than with the uniform twist. The 4·7-inch bronze breech-loader with increasing twist ending with thirty calibres showed a slight superiority to the same gun with uniform twist, but this was not maintained with another cast-iron gun of the same bore with a final twist of 35 calibres. In face of the very slight and doubtfully advantageous results obtained, it was decided to adopt the uniform twist.

Experiments were made with cast-iron guns heavier than the hooped guns in the hope of being able to produce the large

number required for defence more economically. The charge being reduced, the ballistic qualities were diminished. Other experiments were made with the object of making the gun-blocks of steel of Italian manufacture. In 1883 the Gregorini firm delivered two 4·7 inch guns, one in steel, not oil tempered, the other tempered. The analysis of the metal showed a want of uniformity in the first; after firing 1,200 rounds with normal charges, and others giving a pressure of over 16 tons per square inch, the powder chamber was eroded, and the diameter increased 0·27 inch.

The second gun was fired in comparison with two Krupp steel breech-loading guns. After 1000 rounds the Krupp guns were deteriorated in such a manner as to interrupt the trial, the Gregorini, though slightly damaged, was able to continue firing. The results showed that these guns could be supplied by the national industry.

After numerous attempts to check the recoil of the siege-gun carriages by means of hydraulic brakes, or compression of springs, which were unsatisfactory, a brake acting on the tires has been adopted with advantage, also doing away with the necessity of attachments for the hydraulic brake in the earthworks or parapets.

In a very short time all the siege guns will use powder of 0·27 to 0·43-inch cube in place of the progressive 0·78 to 0·94 inch powder, because, though the latter gives slightly superior results, it cannot be employed in mortars and howitzers, so for simplicity only one kind of ammunition will be employed. Experiments are in hand to determine a modification of the rear ring of the projectiles in order to fix their position more accurately in the bore. A base fuze is being tried for the 4·7-inch bursting shell.

The navy having shown by experiments the superiority of steel shell over those in iron, it was attempted to replace the chilled iron 4·7-inch shells with steel made in the country. In 1884 a trial was made of two Gregorini shells, and two of Krupp's, against a chilled plate placed at 131 feet from the gun. The charge was 15 lbs. 6 ozs. of progressive powder. The ogival headed Gregorini indented the plate to a depth of 0·5 inch by 2·36 inches diameter, causing three short and very fine cracks; the Krupp shell made a hole 7·87 inches deep by 11·8 long, with five large cracks. A cylindrical projectile of each maker was fired, the Krupp doing most damage. As the result of the experiments it was determined to use chilled iron until steel shells equal to the foreign shells could be made in Italy.

Platforms are used for the 4·7-inch, and 5·9-inch siege guns; they are composed of two parts, the forward portion being horizontal for a length of 13 feet 3 inch and the rear portion for 6·6 inches is inclined at the rate of 1·91 inch per foot. They are composed of timber. For the guns of position there are five types of platform, viz., (1) for the barbette carriage, placed on the earth; (2) similar to the last, but with reduced range of fire; (3) with masonry foundations; (4) similar to 3, but with reduced range of fire; (5) casemate platform. The masonry platforms

are only intended for works that will be permanent throughout the operations. Provision was originally made for a 7·48-inch hooped cast-iron rifled breech-loader as a siege- and position-gun, but as an 8·25 howitzer was adopted, it was decided to make the gun of the same calibre. For economical reasons it was made of cast-iron, not hooped. The weight is nearly 8 tons 7 cwts. It fires a shell weighing about 174 lbs. with a bursting charge of 10·46 lbs., or a shrapnel of 209·6 lbs. An initial velocity of 1,352 feet is obtained from this gun, without exceeding about 10½ tons chamber-pressure. With an angle of 30° the range is over 8,750 yards. In this gun the best results have been obtained with progressive powder of 0·78 to 0·94 inch cube; the smaller powder would not give the velocity without excess of pressure, and the range was about 550 yards short. But for the same reason as in the case of the other guns, viz., simplicity of service, the smaller powder is likely to be adopted.

A metal carriage has been made at Turin for this howitzer which allows of firing at angles of $-5°$ to $+32°$. The platforms are similar to those for other guns. The 4·7-inch and 5·9-inch guns were fired for penetration in earth and sand, and also against masonry: the following results were obtained. The 4·7-inch bronze gun made a hole 39·375 inches deep in a brick wall when the striking force of the projectile corresponded to a velocity at impact of 1,076 feet, and a range of 656 yards. Under the same conditions seventy-two rounds were necessary to make a hole in a stone wall 9 feet 10 inches thick. The 4·7-inch cast-iron and steel breech-loading guns are a little more powerful. The 5·9-inch cast-iron gun made a hole 39·375 inches deep in a brick wall when the velocity on impact was 1,378 feet, at a range of 765 yards; whilst a stone wall 9 feet 10 inches thick was destroyed for a width of 13 feet in twenty-eight rounds.

J. H. R. W.

On Magnetization. By E. E. N. Mascart.

(Comptes rendus de l'Académie des Sciences, vol. cii., 1886, pp. 991–995.)

When a feebly magnetic and isotropic body is placed in a uniform field, it takes a magnetization parallel to the field, and its coefficient of magnetization k is the ratio of the magnetic moment per unit of volume, or the intensity of magnetization to the intensity of the field. With very magnetic substances, as iron, nickel and cobalt, on the contrary, we should take into account the reaction produced by the induced magnetism, and the preceding definition is only applicable for cylinders of indefinite length magnetized longitudinally, or for closed rings. The calculation of the magnetizing force in function of the external field is very simple in the case of the sphere, of the ellipsoid, or of an indefinite cylinder magnetized transversely; but, unless with very elongated ellip-

soids, the coefficient of magnetization may vary within very wide limits without sensible modification of the magnetic moment of the body. The least defects of homogeneity are then of considerable influence. The coefficient of magnetization is often determined by the use of cylinders arranged parallel to the field, that are assimilated to indefinite cylinders, or to ellipsoids of the same length and same median section; there is then measured either the magnetic moment of the body, or the induced discharge in a bobbin surrounding the mean section when the magnetism is reversed. With rings there can be used only induced discharges, and generally the coefficients obtained are much higher. The question then arises whether one of the methods is defective; for example, whether there is produced with closed rings a particular phenomenon that exaggerates the effects of induction. To resolve this problem the Author has employed, with the same metal, closed rings and a series of cylinders in which the ratio of the length to the diameter varied between very wide limits; and the details and the theoretical consideration of the experiments are given. It is found that two mean coefficients obtained by experiment, differing widely for short cylinders, approximate more and more as the length of the cylinder increases. At the same time their greatest values correspond to the more feebler fields. Finally, the values of these coefficients furnished by very long cylinders are equal to the coefficient k given by closed rings. The knowledge of these mean coefficients referred to, furnishes a correct means for calculating the effect of the magnetism induced by the earth, on the oscillations of a magnetic bar, in the observations relative to the absolute measurement of the terrestrial field.

P. H.

Some Practical Formulas for designing Electro-magnets.

(Centralblatt für Electrotechnik, vol. viii., 1886, pp. 155–175.)

Given the dimensions of an electro-magnet, what will be its magnetic moment for a given strength of current? This is the question, to the practical and at the same time simple solution of which the equations given by the Author will lead. From laws empirically determined by various authorities, are obtained equations which combined give for the magnetic moment the expression $y = k \sqrt{l^3 d} . ni$, where l and d are the length and diameter of the core; n the number of convolutions of the wire, through which flows the current of intensity i; k is a constant, the mean value of which, from the Author's own experiments, is 0·135. The saturation-point is given as 212·5 C. G. S. units per gram, or for iron cores 1298 $l d^2$; and if there are m windings per centimetre of length of the core, then the percentage of saturation $= 0{\cdot}0104 \left(\frac{l}{d}\right)^{\frac{3}{2}} m i$. These formulas apply to uniform cylinders, but the effect of adding

pole-pieces is discussed, and apparently increases the percentage of saturation, but reduces the magnetic moment as compared with a uniform cylinder of the same weight; an experiment on this point, given in the Paper, results in an approximate expression

$$M' = M \left(\frac{P + 2p}{P}\right)^{\frac{5}{3}}$$

where M′ is the moment of the magnet with added pole-pieces of the weight p, and m the moment of the uniform cylinder alone of the weight P.

F. J.

On a New Method for Determining the Time of Oscillation of a Magnet. By G. Hansemann.

(Annalen der Physik und Chemie, vol. xxviii., 1886, p. 245.)

This method, which can be adopted for any similar purposes, consists of an ingenious application of photography for recording the differences of agreement in position between the magnet under observation, and a seconds-pendulum. The magnet is provided with a mirror in the ordinary way, by reflection from which the divisions of a scale mounted before it can be read off in a telescope. A small mirror fixed to the pendulum and parallel with its plane of oscillation, reflects when at rest the beam of an electric-light on to a prism, provided with a broad slit crossed by a narrow vertical bar; from the prism the light is reflected on the mirror of the magnet, from which, when near its neutral position the barred slit is focussed in the small photographic camera specially constructed for the purpose. The slide of the latter is furnished with a micrometer screw, so that the plate can be moved through a known distance between any two exposures. The elongations can be read on the telescope in the usual way, and by measurement of the distance between the images on the negative, the number of oscillations of the magnet corresponding to a given number of those of the pendulum, can be accurately determined, if the times of exposure are chosen when the pendulum and magnet are both near their positions of rest. This method naturally admits of extreme accuracy in the determination of the quantities sought for, besides reducing the time required as compared with the ordinary methods. The description of the apparatus with diagrams appended, as well as the calculations necessary for educing the results from the observations, are given in full detail.

F. J.

Relation between the Coefficient of Self-induction and the Magnetic Action of an Electro-Magnet. By — Ledeboer.

(Comptes rendus de l'Académie des Sciences, vol. cii., 1886, p. 1375.)

The magnetic moment and the coefficient of self-induction of a coil surrounding an iron core were simultaneously determined, the former by Gauss's, and the latter by the Author's method, to find out to what degree the theoretical proportion between the magnetic field and the product of the coefficient of self-induction into the intensity of the current in the coils exists in practice. The results are given in diagrams. For a coil without a core, the magnetic moment and the extra current are represented by a straight line, which is in agreement with theory; the coefficient of self-induction, being constant, is represented by a straight line parallel to the axis of abscissas.

For a coil containing an iron core, the two curves are found to be similar, and superpose when the ordinates are reduced in a given ratio. In this case the two effects are proportionate.

A second set of experiments was made upon a system of inductors similar to that of a Siemens dynamo, having all the dimensions reduced in the same proportion. Curves indicating the variations of the intensity of the magnetic field, and of the extra current, are given, and the latter show how the field becomes saturated.

E. F. B.

Practical Instructions relative to Accumulators.

By G. Planté.

(La Lumière Électrique, vol. xx., 1886, p. 247.)

The method of separation of the electrodes is of great importance. Since 1860 the Author has employed several arrangements, but the last is the most simple in which the lead-plates are kept apart by a series of double buttons of gutta-percha, about 10 centimetres distance from one another. To attach these buttons the odd or even plates are perforated. Against each perforation, on both sides of the plate, are applied small cubes of gutta-percha about a centimetre thick, previously softened by heat so as to allow the percha to penetrate the hole; the two cubes unite and form a fixed and solid bottom. Only the odd or even plates are thus provided.

The lead-plates are suspended by the aid of lead wires to bars of wood resting on the edges of the cells. So that these wires may not touch, the wires of the odd and of the even plates are arranged at different intervals. The lugs of the plates are varnished with a

resinous mastic, and furnished with screws of copper or of type-metal, connected by wires to metallic pieces uniting a certain number of plates. The independence of each plate is thus secured; a single plate may be removed without disarranging the remainder.

In 1872 the Author advised attention to be paid to galvanic deposits of lead. Because there have been obtained only spongy, lamellar, or arborescent deposits, without coherence or adherence, it does not appear impossible to obtain a deposit of lead, united, thick and coherent, similar to that deposit obtained in plating copper and silver. If a good deposit could be produced, it would be an interesting result, for this deposit would be easily oxidisible or reducible throughout its depth, in consequence of the porosity of electro-chemical deposits. It could also be produced on any support, as a plate of mica, thus obtaining electrodes of exceptional lightness. But it is to be feared that, by reason of the manner in which electrolytic actions operate, in spite of the apparent adherence presented by a good electro-chemical deposit, the work of electrolysis, tending always to operate by the shortest road, connection between the metallic or metallised support would cease. The Author has, therefore, thought the more perfect mode of formation is that of peroxidising or reducing the metal of the electrode itself, and that electrodes well "formed" in this manner, presenting no deposit for disaggregation, are so to say indestructible.

P. H.

The Aymonnet Battery. By B. Marionovitch.

(La Lumière Électrique, vol. xx., 1886, p. 204.)

This battery is employed to light electrically the Gobelins theatre, but it is stated that electric lighting is not the main object of the generation of the current, which is used to produce a chemical product in considerable demand. The battery, as arranged, consists of two series of elements, a series of large elements A, with negative electrodes of iron, and positive electrodes of carbon, the exciting liquid being dilute aqua regia. These elements communicate so that the exciting liquid can flow through them in succession. From the end cell it is pumped to the beginning of a series of smaller cells D, also provided with iron and carbon electrodes, but in which the exciting fluid is perchloride of iron. From the end cell of this series the liquid flows into a tank where it forms a commercial product, or may be again used in the cells D. In the elements A the action is

$$2\,Fe + 3\,H\,Cl + NO_5\,HO = Fe_2\,Cl_3 + 4\,HO + NO_2.$$

At the same time there is formed a small quantity of nitrate of iron and sesquioxide of iron, which is dissolved in the perchloride of iron. A fan, driven by a small Gramme dynamo, draws the

nitrous vapours into a chimney filled with coke and furnished with a water-spray. The binoxide of nitrogen is transformed into hyponitric acid and nitric acid, so that the latter is nearly wholly regenerated. The liquid issuing from the elements A, and pumped into those of series D, is perchloride of iron, containing small quantities of nitrate of iron. In the elements D there is formed principally $4\,Fe_2\,Cl_3 + Fe = 3\,Fe_3\,Cl_4$ and partially $Fe_2\,Cl_3 + Fe = 3\,Fe\,Cl$; $3\,Fe\,ONO_5 + 5\,Fe = 4\,Fe_2\,O_3 + 3\,NO_2$; the binoxide of nitrogen dissolves in the protochloride of iron and the sesquioxide of iron in the magnetic perchloride of iron $Fe_3\,Cl_4$, which is the commercial product. When the production exceeds the demand, this product is allowed to remain in contact with air and water, when the following reactions occur: $2\,Fe_3\,Cl_4 + 8\,HO + O = 3\,Fe_2\,O_3 + 8\,H\,Cl$; $Fe_2\,O_3 + 3\,H\,Cl = Fe_2\,Cl_3 + 3\,HO$, whilst the binoxide of nitrogen is transformed into nitric acid. There remains in the receptacle where this action takes place, a deposit of sesquioxide of iron, and there is returned to the small elements dissolved perchloride of iron with a certain quantity of nitric acid. The product issuing from the elements D is a very energetic disinfectant; it is also employed in dyeing and in agriculture. The chief interest lies in the production of what Mr. Aymonnet terms the magnetic perchloride of iron, a new product as confirmed by Mr. Würtz.

P. H.

On Recent Types of Electrical Cables. By — Frischen.

(Elektrotechnische Zeitschrift, 1886, p. 236.)

Gutta-percha has up to the present maintained its position as the best insulator of electrical conductors, but unfortunately it softens at comparatively low temperatures, and requires a protective sheathing against mechanical damage. The adoption of the so-named "lead" cables, recently introduced by Messrs. Siemens and Halske, obviates these failings, while they are cheaper, and not inferior in electrical qualities, to gutta-percha. The conductor is covered with a layer of jute, which is carefully desiccated and saturated with some insulating compound, which is fluid when heated, the whole being enclosed in a leaden tube, which is formed under hydraulic pressure from a solid block of cold lead. This process of manufacture is applicable to conductors of any size, from the largest to the smallest. The unit lengths, limited by the capacity of the hydraulic press, are perfectly joined together by ordinary methods without any difficulty. Usually the covering of the lead with a layer of "compounded" jute is sufficient, but for special purposes the cable can be iron-sheathed with wires, or, better still, with overlapping spirals of strip. For electric light conductors of large section, an insulated conductor is laid up in the copper strand, to serve for the measurement of tension at any given point.

In installations the joints between the main and branch wires are made with iron junction-pieces, which, after the conductor is joined, are made damp-tight by a filling of asphalt, or some such material. For multiple connections iron boxes are used, the introductions for the cable ends and the cover being packed with india-rubber. To eliminate the effect of alternate currents on the neighbouring circuits, a return wire must be used, and this is formed by a conductor of annular section surrounding the main conductor, and enclosed in the same outer covering.

For telephone cables to eliminate electro-static disturbance, it is sufficient that each conductor be surrounded with a metallic shield, *e.g.*, tinfoil or copper; but in the case of electro-magnetic disturbance the protection is not so easily effected, and the metallic sheath must act also as the return wire, and its resistance be approximately equal to that of the internal conductor; this, however, by increasing the electro-static capacity of the circuit, reduces the clearness of telephonic articulation.

Special experiments have for some time been in progress as to the best type of cable for such communication, the latest manufactured being the "fan" cable, where the conductors lie in concentric circles, those in the same circle being separated from each other by copper strips, extending fan-wise from the centre.

After the reading of the Paper, Dr. W. Siemens mentioned that he was led to this use of jute by Sir W. Thomson's statement that vegetable fibre in a dry state was an excellent insulator.

F. J.

Experiments on the Action of Solenoids on Iron Cores of Varied Forms. By Dr. T. Bruger of Darmstadt.

(Electrotechnische Zeitschrift, 1886, p. 199.)

This is an account of a comprehensive investigation into the attraction by a solenoidal coil, through which a current is flowing, of iron cores of different longitudinal sections. The results plotted in diagrammatic curves show that, with cores of a length more than double that of the solenoid, the point of maximum attraction only slightly alters in position, and occurs when the lower ends of core and solenoid coincide; and further that, for a cylindrical core of even section, this point is independent of the strength of the current. With cores formed of two cones placed base to base, the curves of attraction for different positions, sugar-loaf in form, are not essentially altered; but with single cones, the small end entering first, the point of maximum attraction varies somewhat with the strength of the current, but the apex of the curve is considerably lowered, so that the fall on each side of the maximum is not so rapid. Thus if the stroke of the core be limited to about one-third of its whole length, and be across the maximum point, the variation of attraction for cylindrical, biconical, and conical cores

is about 50, 40, and 15 per cent. respectively from the maximum. Experiments to determine a core which would give an attraction of practically constant values for some considerable portion of its length, led to the production of a core of peculiar and special form, a cone of slight taper with swellings at definite points (figure illustrated), with which for rather more than a third of its length the attraction did not vary more than 5 per cent.; a trial of the reproduction of such a core, by mechanical copying in the workshop, resulted in a curve not quite so regular, and its weight was somewhat less.

Similar curves, but of course with considerably less attractive force for the same current, were obtained with cast-iron cores; annealing the wrought-iron core did not introduce any practical difference.

F. J.

Safety-Fuzes for Electric Circuits. By G. Roux.

(L'Electricien, 1886, p. 419.)

In electric light installations it is usual to insert a fusible safety-plug, which melts, and so interrupts the circuit before any damage can arise from overheating the conductors. The equation which gives the relation between the size of a wire of circular section of the fusible material, and the current by which it will be fused, is,

$$\frac{a\,l}{\pi\,r^2}\,\mathrm{I}^2 = c\,(\theta - t)\,2\,\pi\,r\,l,$$

the left-hand member representing the heat developed by the current of intensity I through a wire of length l and semidiameter r, a being the specific resistance of the material; and the right-hand member representing the radiated heat, θ being the temperature of fusion (for lead, 335° Centigrade, or 635° Fahrenheit), t that of the surrounding air (say 15° Centigrade, or 59° Fahrenheit) and c the coefficient of cooling, from which

$$\mathrm{I} = \sqrt{\frac{2\,c\,(\theta - t)\,\pi^2\,r^3}{a}} = k\,r^{\frac{3}{2}},$$

where k is a constant, and can be determined by experiment on wires of length sufficiently great to neglect the influence of the connections at either end, and for lead k equals 100.

Experiments by Mr. Grassot show that for lengths above 8 centimetres (3·15 inches) and of diameters between 1 and 0·5 millimetres ($\frac{1}{25}$ to $\frac{1}{50}$ of an inch) the results agree exactly with the values calculated by the equations given above; but the current necessary for fusion increases with the reduction of length, which is due to the cooling-effect of the connecting clamps.

F. J.

Experiments in Thermo-Electricity.

By L. Pilleur and E. Jannattaz.

(Journal de Physique, 1886, p. 172.)

The Authors found that thermo-electric currents were produced in conductors which are rolled out so as to have a schistose texture. Experiments were made on zinc, tin, iron, and copper. A point A was heated in the centre of the plate, and one connection was made at a point B situated on the other face, at the extremity of the line joining the hot point, across the grain of the metal, and the other at a point C situated at the extremity of the line joining the hot point A along the grain of the metal. The current has always been from B to C through the external circuit. The intensity of the current for each metal depends on the amount that the metal is drawn out. Thus zinc drawn out to four times its length has given a weaker current than one drawn out six times; zinc gave the strongest, and copper the weakest currents. The currents themselves are difficult to determine, doubtless owing to the ease with which they can pass through the substance of the plate; much more intense effects can be obtained by cutting the two extremities of the square out of the metallic plate, a square of which one branch takes the grain of the metal in its length, and the other across, and connecting by means of an external circuit.

E. F. B.

On the Electrical Properties of German Silver.

By G. B. Prescott, Jun.

(Electrician and Electrical Engineer, New York, 1886, p. 126.)

The Author is surprised that the early, and even later experimenters, with hardly any exception, fail to mention the proportion of the constituents (copper, nickel, and zinc) of the alloy termed German silver, though it is well known that its electrical properties vary considerably. Thus a Table, wherein are contained the results culled from various sources, shows the specific resistance of German silver to vary from 10,672 to 17,834 lbs. per mile-ohm.[1]

In a Paper recently read before the Royal Society of London, Mr. J. T. Bottomley has described a new alloy termed Platinoid, invented by F. W. Martino, as consisting practically of German silver, with 2 per cent. of tungsten added, and as having a specific resistance one and a half time that of German silver, while its temperature coefficient is only half as much. This discovery

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[1] Weight in lbs. of 1 mile of wire having 1 ohm resistance.

being of such importance, an investigation of the variation of the proportions of the alloys termed German silver, as affecting the electrical properties, was undertaken by Mr. Edward Weston. His results show that the addition of tungsten has not the slightest effect on the electrical properties, while the resistance varies almost directly, and the temperature coefficient inversely as the quantity of nickel; the presence of zinc merely renders the alloy more ductile.

A Table exhibiting Mr. Weston's results gives the quantities of copper, nickel, and zinc in the alloy, and the corresponding specific resistances at the standard temperature. This varies from 11,572 to 24,485 lbs. per mile-ohm, the proportion of nickel being 12 and 34 per cent. respectively in the two cases.

The importance to manufacturers and others of specifying the particular alloy required is specially dwelt on; thus, for example, double the price could be paid for wire having twice the specific resistance.

F. J.

Electric Conductivity of Chloride of Potassium solutions.

By E. Bouty.

(Comptes rendus de l'Académie des Sciences, vol. cii., 1886, p. 1097.)

The Author deduces the specific resistance of a normal solution of chloride of potassium containing 74·59 gram (an equivalent) of the salt per litre, to be 15·415 ohms.

P. H.

Law of Efficiency corresponding to the Maximum of Useful Work in Electric Distribution. By — Vaschy.

(Comptes rendus de l'Académie des Sciences, vol. cii., 1886, p. 1235.)

If there be employed an electric generator, battery, or magneto-machine, of constant electromotive force E to heat a conductor of resistance R, to charge an accumulator of electromotive force E′, or to produce mechanical work, the energy utilized ($R i^2$ or $E' i$, as the case may be) varies with the values given to E or E′, and this energy is at a maximum when the fall of potential utilized ($R i$ or E′) is half the electromotive force E. It results that the efficiency corresponding to the maximum of useful work is $\frac{1}{2}$. This is Jacobi's law.

When the generator is a dynamo, the electromotive force of which is a function of the current traversing it, this law is no longer exact. It is replaced by another more complicated. These laws have been demonstrated for only simple circuits. The

Author proposes to generalize them by considering any electric network with a number N of branches, including: (1) generators of electromotive forces $E_1, E_2 \ldots . E_N$, and of resistances $r_1, r_2 \ldots r_N$ (comprised by, besides other inert resistances, connecting-wires, &c.); (2) resistances to be heated, $R_1\ R_2 \ldots .$ (lamps, &c.), or contrary electromotive forces to be overcome, $E'_1, E'_2 \ldots .$

If $i_1, i_2 \ldots .$ are the currents in these several branches, the energy expended is

$$W_m = E_1\, i_1 + E_2\, i_2 + \ldots = \Sigma\, E\, i.$$

The energy utilized may be written under the form

$$(2)\quad W_u = \Sigma\,(E - r\,i)\,i.$$

First case.—If the electromotive forces $E_1\ E_2 \ldots .$ are constant (batteries or magnetos)—

$$(3)\quad d\,W_u = \Sigma\,(E - 2\,r\,i)\,d\,i = 0.$$

Considering this equation in connection with Kirchhoff's law, the Author deduces that the efficiency $\frac{W_u}{W_m}$ corresponding to the maximum of W_u is equal to $\frac{1}{2}$; and he also arrives at the same result by another method. Thus W_u is maximum when the fall of potential E′, utilized in each branch, is equal to half E. Then—

$$\Sigma\, E\, i = 2\,\Sigma\, E^1\, i \text{ or } W_m = 2\, W_u,$$

which is Jacobi's law generalised. It applies even when the fall of potential E′ is due to an intercalated resistance R. The condition $E = 2\,E'$ becomes in this case $E = 2\,R i$.

Second case.—If the electromotive force E of the generators depends upon the current i traversing them (following a known law that may be represented graphically by a characteristic), the condition of maximum of W_u becomes

$$(3^1)\quad d\,W_u = \Sigma\left(E + i\frac{d\,E}{d\,i} - 2\,r\,i\right)d\,i = 0;$$

and from the previous consideration the Author deduces

$$W_m = 2\,W_u + \Sigma\,\frac{d\,E}{d\,i}\,i^2.$$

The efficiency here is no longer half, the work expended W_m exceeding double the work utilized W_u by the value $\Sigma\,\frac{d\,E}{d\,i}\,i^2$, which may be considered as the work absorbed by the fictive resistances $\frac{d\,E}{d\,i}$ placed in the several branches of the network. These resistances may be some positive, if the electromotive force E increases

with the current i (ascending part of the characteristic), or negative (descending part), or nil if E is maximum (vertex of characteristic). The efficiency $\frac{W_u}{W_m}$ corresponding to the maximum of useful work may then be inferior or superior, or even, exceptionally, equal to half. To learn its value, it is required to calculate the currents i_1, i_2 . . . ., upon which depends the quantity $\Sigma \frac{d\,E}{d\,i} i^2$.

P. H.

Electric-Lighting in Milan.

(Il Politecnico, March–April 1886, p. 180.)

No city in Europe possesses so large and complete an installation of electric light as Milan. The works were commenced in October 1882, and the lighting was inaugurated in June 1883. In September 1883 seven hundred lamps were supplied from the central station. On the 1st of January, 1884, the theatre of La Scala was lighted, and in April of the present year there were 7,598 glow- and 96 arc-lamps. The latter range from 1,400 to 5,000 candle power. Reducing the whole of the lights to the equivalent of sixteen candles each, the number of lamp-hours in the first three months of the present year was 3,141,850 (or double the quantity during the corresponding quarter last year). The receipts of the quarter were about £4,800. The greatest number of lamps burning at a time is at about eight o'clock in the evening, when it reaches 7,100, diminishing to 540 at about two in the morning. The rates charged are as follows: For each lamp of 16 candles an annual charge of 28*s*., and a rate of $\frac{3}{8}$ of a penny per hour (equivalent to $\frac{8}{15}$ of a penny per ampere.) For each lamp of 10 candles the annual charge is 18*s*., and a rate of $\frac{4}{15}$ of a penny per hour. Lamps of 8 and 32 candles in proportion. At first, contracts were made at a charge per annum for each lamp calculated approximately on the above rates, but a system of payment by meter has since been introduced, and is largely adopted, the meters giving results of the greatest accuracy. The greatest length of any conductor is about 2,100 feet. There would be no technical difficulty in prolonging this considerably, but the cost of the light would be greater for glow-lamps but not for arcs. The Thompson-Houston machines and lamps are used for the arc-lights.

W. H. T.

On the Theory of the Telephone. By E. Mercadier.

(Journal de Physique, 1886, p. 141.)

The Author considers the diaphragm of the telephone, both as regards its elasticity and the transformation of energy which results from its movements. As regards the former, he concludes that the mechanism, owing to which telephonic diaphragms move, is analogous, if not identical, with that by which solid bodies transmit to one of their surfaces all the vibratory movements produced by air in contact with the other surface, whether simple or complex, successive or simultaneous, and having a continuous or discontinuous period. In diaphragms of sufficient thickness this kind of motion would be alone produced, the diaphragms acting as simple transmitters of vibratory movements, independently of their geometrical form. But as regards thin diaphragms, they would always act in the same manner, and also at times in a more active, and, as it were, special manner, according to the laws of elasticity relating to their geometric forms, modified to a certain extent by the heterogeneity of their molecular constitution, and the more or less regular way in which they are fixed. In this manner one may account for the general and complex movements of transmitting telephonic diaphragms, allowing of the reproduction of a continuous scale of successive sounds, superposed by musical chords or series, such as are required in the explanation of timbre; and in this way may also be explained the increase produced by the use of very thin diaphragms in certain points of the scale, and the alterations of timbre generally accompanying them.

As regards the use of the diaphragm from the point of view of the transformation of energy resulting from its movements, the Author materialized, so to speak, the magnetic field with iron filings scattered over the pole or poles of a telephone, and obtained the following remarkable result, that musical sounds and articulate speech were reproduced, from which he concludes that rigid metallic diaphragms are not indispensable for the production of telephonic effects, but are useful in increasing their intensity, by presenting a larger number of magnetic molecules per unit of volume to the action of the interior forces, or by producing a greater concentration of the lines of force of the magnetic field.

Hence for the reception, as well as for the transmission of sounds, the rigidity of the diaphragm is not indispensable; it is necessary to give a material support to the rapid modifications produced in the magnetic field of the receiver by the current induced in the helix. This may be done simply by using iron filings, which place themselves in the lines of force; the diaphragm serves to increase the intensity of the effects, in the first place by concentrating the lines of force of the magnetic field, and in the second place by augmenting the mass of air to which is trans-

mitted the movements resulting from the transformation of energy which operates at various points of the magnetic field.

As regards thick and thin diaphragms, in the latter there is lost in quality that which may be gained in quantity or intensity, but there is always a certain thickness of diaphragm which, for a field of given intensity, gives a maximum telephonic effect. This result, analogous to that found in other electromagnet phenomena, may explain the want of success of many attempts made to increase the intensity of the effects of electro-magnetic telephonic receivers.

E. F. B.

On Telephony and the Operation and Functions of the Induction-Coil in Transmitters, and, Some Recent Advances in Telephony.

By T. D. Lockwood.

(Electrician and Electrical Engineer, New York, 1886, pp. 124, 164, 204, 218.)

After a short account of Professor Bell's discovery of the telephone as a transmitter of vocal sounds, the Author alludes to the fact that the currents from the magneto-telephone, generated when it is used as a transmitter, are weakened by the reverse currents generated in the receiving telephone on which it acts. The same effect also follows the use of battery currents, but as these latter are much stronger than the former, they are not affected to the same extent. The direct application to a telephonic circuit of currents, rendered undulatory by some resistance-varying apparatus, is not satisfactory, as the variation of resistance in the apparatus is small compared with the resistance of the line. The Hunnings transmitter is partially successful in this case, as great variations in the resistance of the granulated medium are produced by the air-vibrations, but it requires excessive battery power. The adoption of the induction-coil, however, removes all these objections, as the varying resistance is then part of a circuit of low resistance, and by proper adjustment of the winding of the primary and secondary coils, the effect on the line wire is thus considerably increased. It is remarked that the transmission is also similar in form to that effected by the magneto-telephone itself, as the action of the coil is principally due to the magneto-electric currents induced by the core.

The different methods of arranging the primary and secondary wires on the core, and the maintenance of the latter in a permanent magnetic state, are described and illustrated. The most effective form is that of a horse-shoe for the core, with the secondary coils on its ends, the primary coil being wound either half on each leg or altogether on the bend; the addition of a soft iron armature

across the poles of the horse-shoe increases the induced currents by 25 per cent.

The latter Paper was read before the American Institute of Electrical Engineers, and, among other matter, contains a description of the different methods in use for connecting telephonic exchanges by trunk-wires. The trunk-line must be on the double-wire system; the connection of the subscribers of an exchange, where the wires are only single, can be effected by inserting induction coils at each end of the trunk-wire, the primary coils of which have one end to earth and the other connected at will to any subscriber's line, or instead of using the earth, a special return circuit-wire can be laid down, providing thus a double, but not a parallel return wire, for each subscriber. Where the subscribers are connected by double parallel wires to the exchange, each wire can be connected to the separate trunk-wires without the intervention of the induction-coil.

F. J.

On Recent Progress in Underground Telephone-Wires.

By W. W. JACQUES.

(Proceedings of the Society of Arts of the Massachusetts Institute of Technology, 1885–6, p. 20.)

Ten years ago the number of wires in use for ordinary telegraphic communication in American cities was comparatively small, while electric lighting had not yet come into practical use, and the telephone, the wires connected with which outnumber those used for all other purposes in cities, was entirely unknown. The many objections to overhead wires, the annual cost of repairs to which in cities is not less than 30 per cent. of the first cost of construction, are well known; and in their own interest, quite as much as for the public benefit, the American Bell Telephone Company have spent large sums in endeavouring to find a practical method of placing the wires of an exchange system underground.

If two or more telegraph wires are bunched together in a cable of such length as that used in large cities, each wire works practically as well as before, and is entirely independent of the neighbouring wires in the same cable. But with telephone wires it was found not only that conversation was very much lowered in intensity, owing to retardation, but also that conversation carried on over one wire was heard with equal facility on all the other wires in the same cable. This may be owing either to direct leakage or to induction, which, though not sufficient to affect even the most delicate telegraphic apparatus in use, is amply sufficient for overhearing in the case of the telephone.

The annexed Table shows the specific inductive capacity and insulation of various insulators. All the measurements were made

on a wire 0·05 inch in diameter, coated with insulation to a thickness of 0·10 inch:—

Cable.	Maker.	Insulation per Mile in Megohms.	Specific Inductive capacity.
Gutta-percha .	Siemens Brothers, London	190	4·2
India-rubber .	Rattier, Paris	170	3·7
Kerite . . .	A. G. Day & Co., New York	150	4·0
Faraday . .	Faraday Cable works, Cambridge, Mass.	15,000	1·6
Patterson . .	Western Electric Co., Chicago . . .	450	3·1
Brooks . . .	David Brooks, Philadelphia	..	2·8

According to this Table, it ought to be possible to talk three times as far with a Faraday as with a gutta-percha cable, and experiment has shown that while conversation over a 2-mile gutta-percha cable was continually disturbed by cross-talk, no such inconvenience was found with a Faraday cable 5 miles in length. German counterparts of the Faraday cable have been in use for six or seven years without any material deterioration in insulating power.

India-rubber and kerite, though extensively used for telegraph cables, are equally unfit with gutta-percha for telephonic work.

The Patterson cable, which under different names has been extensively used for some years past in France, Germany, and elsewhere, consists of cotton-covered wires soaked in paraffin, and drawn into a lead pipe. Unfortunately it has been found that the insulation, though high at first, gradually decreases, and after several years falls so low that cross-talk, due to direct leakage, easily appears.

The Brooks cable consists of copper-covered wires wound with cotton and drawn into iron pipes, which are then filled with petroleum. When the pipes, and the cables before being drawn in, are thoroughly dried, and the pipes filled with dry oil, the insulation is enormous, and the cable gives wonderfully good results for telephonic purposes, being remarkably free both from retardation and cross-talk. But it is almost impossible to make the pipes so tight that the petroleum does not leak out, or water leak in, and consequently the insulation falls continually; and after three or six months, if the cable be of any considerable length, will have fallen so low that cross-talk from direct leakage will be easily heard on all the conductors assembled together. For this reason no value has been assigned to the insulation of this cable, as stated in the comparative Table above given.

It is true that in the Paris telephone exchange, which counts over three thousand subscribers, gutta-percha cables placed underground are used. But these cables are constructed in a peculiar way, consisting of two insulated wires twisted spirally, the current going over one wire and returning over the other. As in each

pair of conductors the equal and opposite currents would tend, either by leakage or induction, to produce equal and opposite currents, or in other words no current at all, in either branch of any neighbouring conductor, there is no tendency to cross-talk. But in addition to the increased cost, owing to two wires being required for each subscriber, there has not yet been devised a real practicable method of connecting a metallic circuit system with a single circuit system, so that conversation could not be carried on between persons in two neighbouring cities, unless the system of each city, as well as the intervening trunk lines, were constructed with metallic circuits.

Although with suitable cables there are no technical obstacles to placing all the wires of a telephonic exchange underground, it would not be economically practical, as the cost for excavating, laying the conduit, and refilling, is nearly as much for one wire as for fifty. But it is practicable to extend wires from the central office underground to a considerable number of points, some one of which shall be easily accessible by a short overhead line from any subscriber's station; and such a system, requiring practically no expenditure for repairs, and being always in good order, would probably in the long run prove more economical than to carry the wires entirely overhead.

W. S. H.

A Registering Hygrometer. By Alb. Nodon.

(Comptes rendus de l'Académie des Sciences, vol. cii., 1886, p. 1371.)

The principle of this instrument is similar to that of Breguet's metallic thermometer, the helix being formed of two substances unequally hygrometric. The inventor finds that the angles through which the spirals unroll are proportional to the hygrometric state of the atmosphere; that ordinary atmospheric variations of temperature have no influence on the indications of the hygrometer; the instrument is absolutely constant, and takes only one minute to place itself in hygrometric equilibrium with the surrounding atmosphere; it may be made as sensitive as desired by a proportional increase in the number of spirals of the helix.

E. F. B.

On Vapour and Cloud. By R. von Helmholtz.

(Annalen der Physik und Chemie, vol. xxvii., 1886, p. 508.)

The theoretical and experimental treatment of the subject in this Paper shows that the formation of cloud in moist air does not commence exactly with the arrival at its normal saturation, but at a somewhat higher point, which depends partly on the fact that the vapour tension over the convex surfaces of the cloud-masses is

greater than over a plain surface. Introducing a correction for such variation, then the formation of cloud is a delicate and accurate test of saturation, provided that the air contains a normal quantity of dust particles, *i.e.*, that it be unfiltered and renewed at intervals, and that it be free from salt particles or acid vapours, which would act chemically on the water-vapour; with these conditions fulfilled, adiabatic cooling affords a ready means for determining the degree of saturation of the air, and thus the vapour-tension of solutions. At low temperatures, say under 30° Centigrade (86° Fahrenheit), the values of the reduction of vapour-tension agree with those obtained by barometric measurements, but at higher temperatures, before sufficient accuracy can be expected, the ratio of the specific heats of water-vapour must be more closely determined.

F. J.

Experimental Researches on the Limit of Velocity of a Gas which passes from a Higher to a Lower Pressure.

By G. A. Hirn.

(Annales de Chimie et de Physique, vol. vii. 1886, p. 289.)

The Author commences with the construction of the various equations that have been proposed to represent the movement of elastic and non-elastic fluids, deducing therefrom the importance and necessity of his researches. All the experiments were made on atmospheric air taken at barometric pressure, increased by that of the charge in the gasometer. Five different forms of orifice were subjected to experiment; two were very obtuse cones formed in the thin metal of the reservoir, two were converging cones, the one at an angle of 13°, and the other of 9° to the axis, whilst the last had a cylindrical tube of glass connected to a converging cone. The experiments made were with the object of determining, in the first instance, the effective section of aperture, and are given in full detail, as well as in a general Table and diagram, and from them the Author criticises the various equations hitherto proposed, and places the experimental and theoretical numbers obtained in Tables in juxtaposition.

As a *resumé* of his experimental work, the Author considers,

1st. That neither Weisbach's law for volumes, nor any previously proposed law, gives even approximately the volume of a gas which flows through a given aperture, from a reservoir where the pressure is P_0 into another where the pressure is $P_1 < P_0$, when P_0 is much greater than P_1, whilst they give almost exact results when P_0 and P_1 are nearly equal.

2nd. That Weisbach's law for velocity is absolutely false, when P_1 becomes very small, or more generally when the ratio of $\frac{P_1}{P_0}$ is very small.

The true law of the flow of gases for any difference of pressure $(P_0 - P_1)$ is, in the Author's opinion, unknown. With his experimental data he might have proposed an empirical law, which would represent the phenomena approximately, but considers such determinations as superfluous in the actual condition of the physical and mechanical sciences.

Of several important considerations resulting from his experimental work, he refers only at present to the kinetic theory of gases.

Suppose a gas, atmospheric air, for instance, to be enclosed in a reservoir and submitted to constant pressure, and that the reservoir is connected up to another in which there is a perfect vacuum, it is evident that the velocity of flow can neither be greater nor less than the specific velocity of the gaseous particles at the temperature of the gas. The theoretical velocity for atmospheric air, passing into an absolute vacuum, is 485 metres per second, whilst the Author has actually obtained a velocity of flow of 6,000 metres against a certain amount of pressure. In the Author's view, the kinetic theory is thus in direct opposition to experimental results.

E. F. B.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1885–86.—PART IV.

LONDON:
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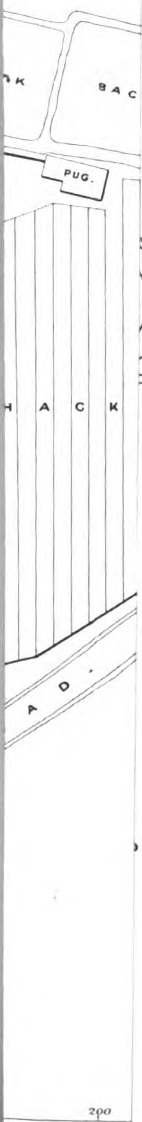

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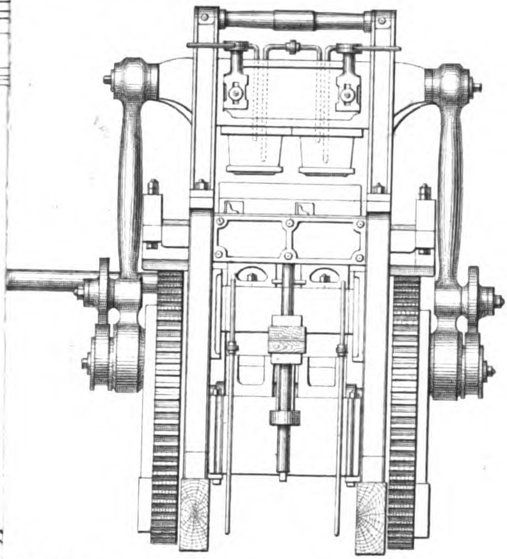

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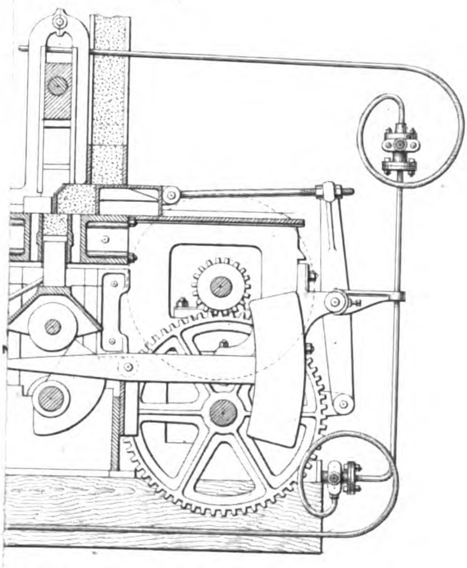

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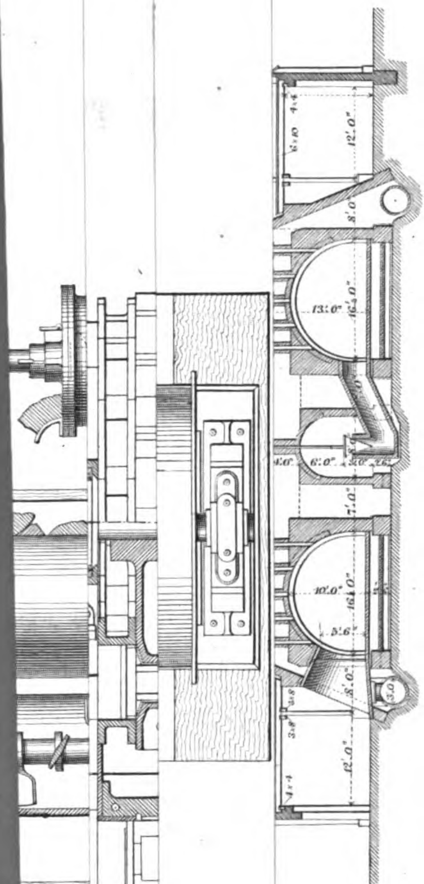

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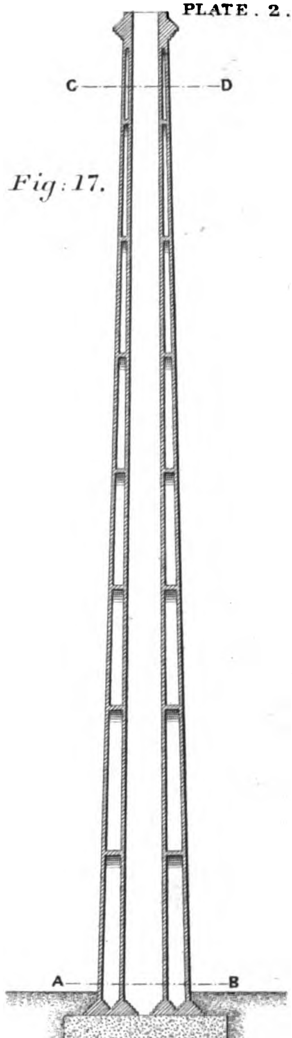

SECTIONAL ELEVATION.

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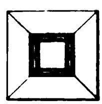

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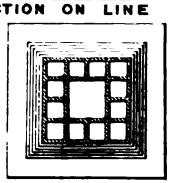

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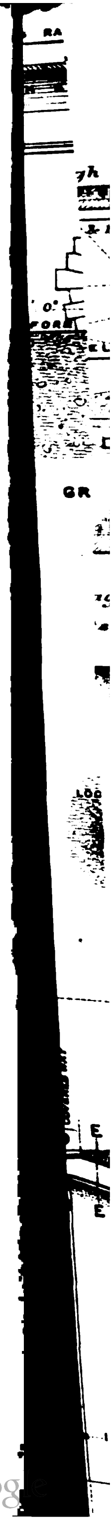

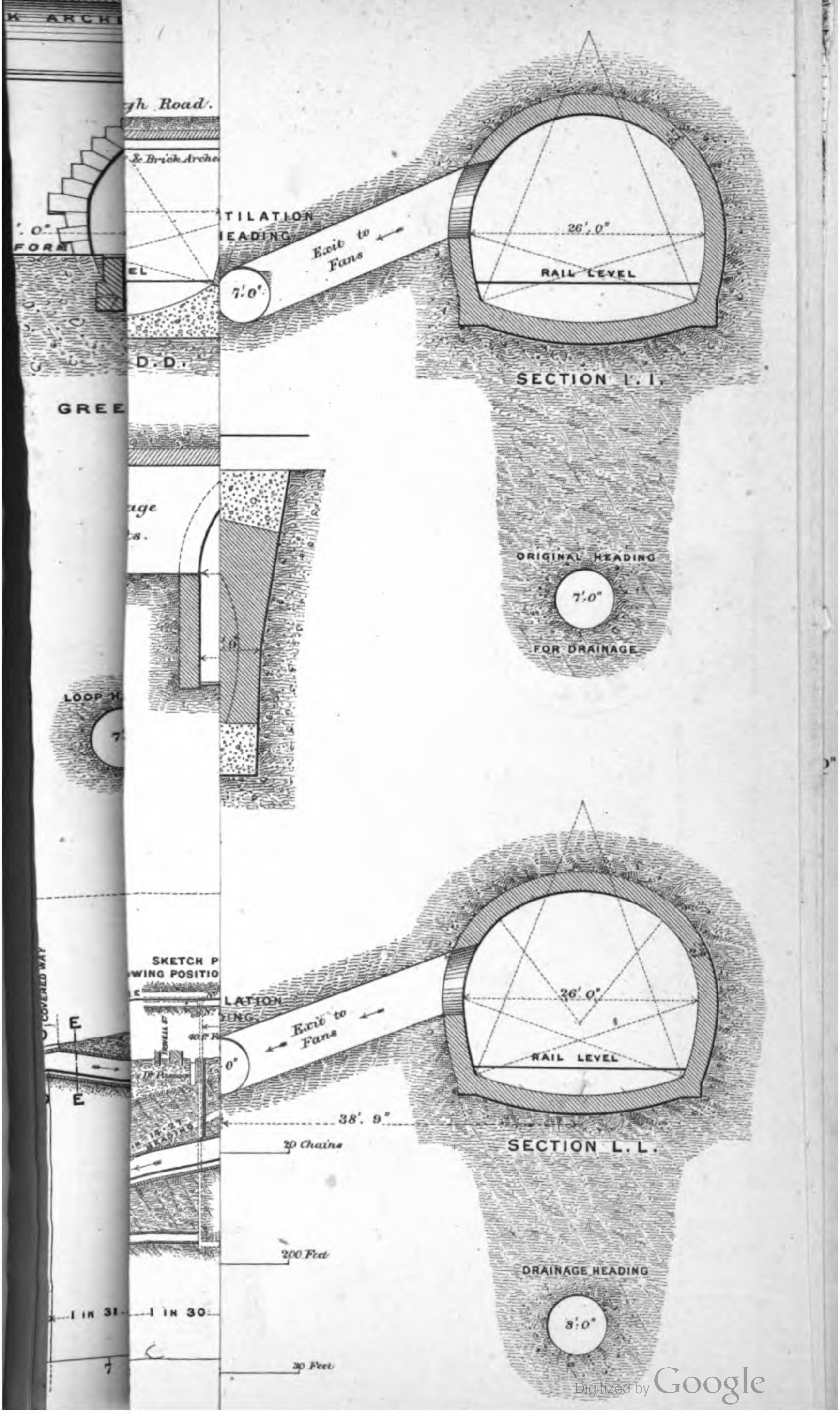
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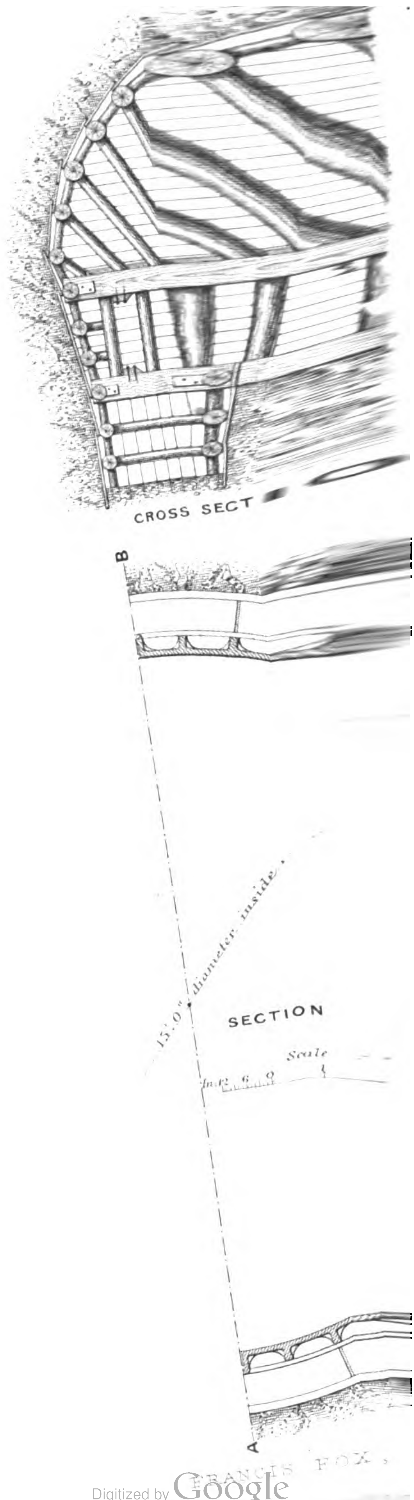
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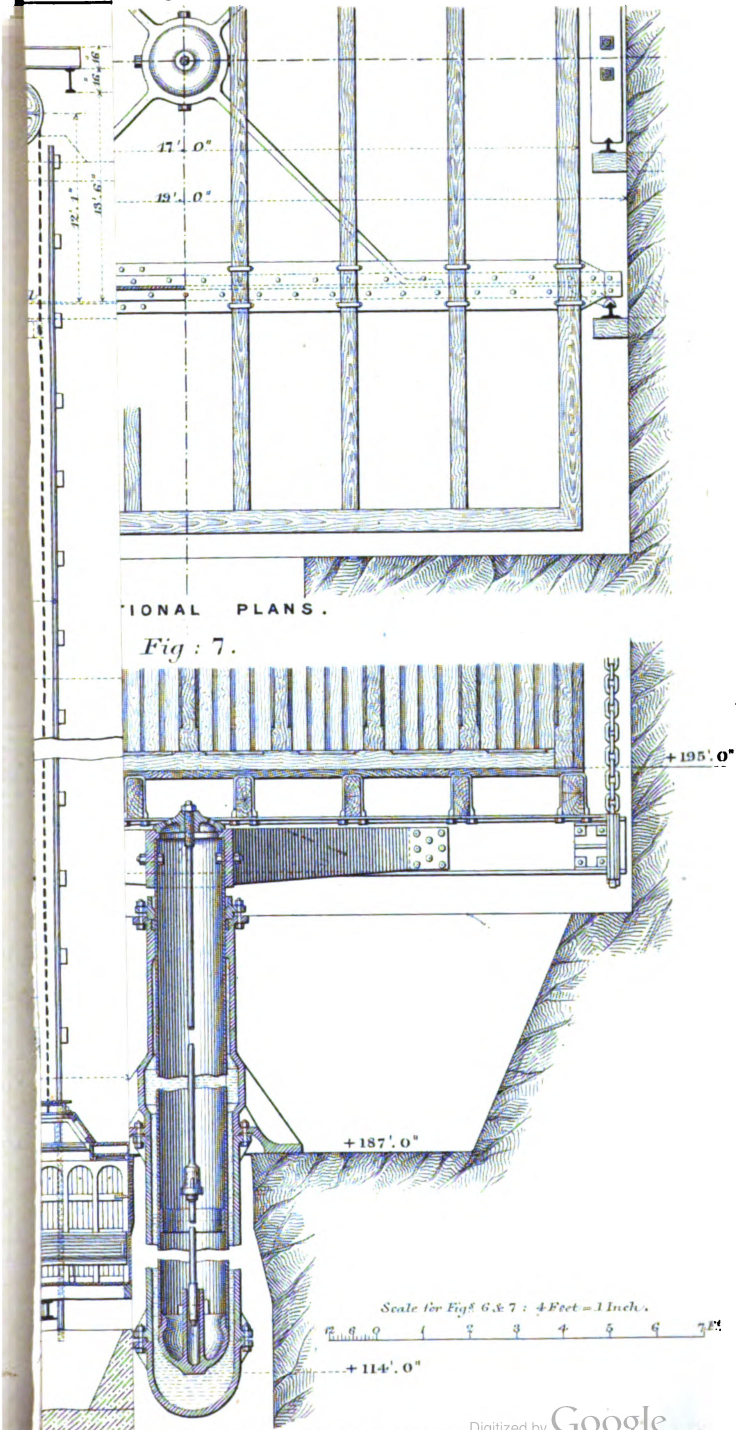

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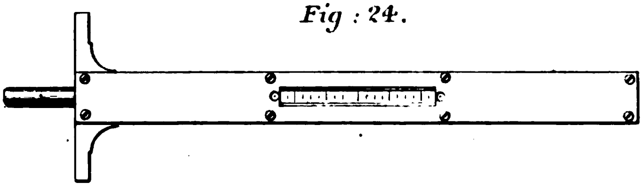

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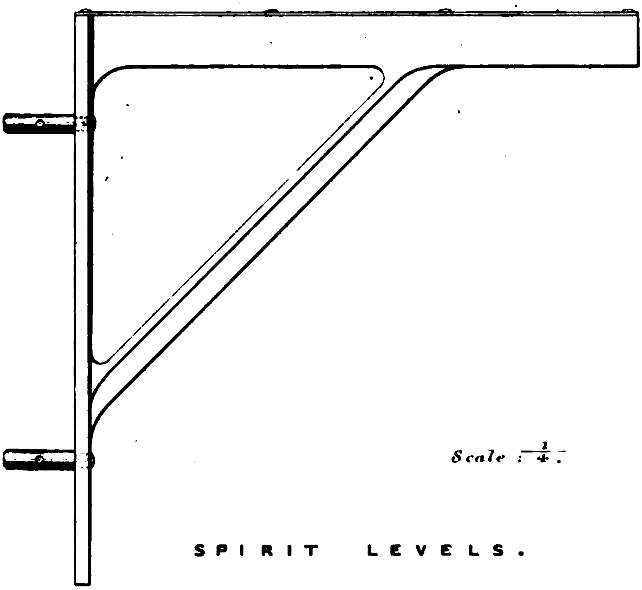

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Fig : 17ig : 20.

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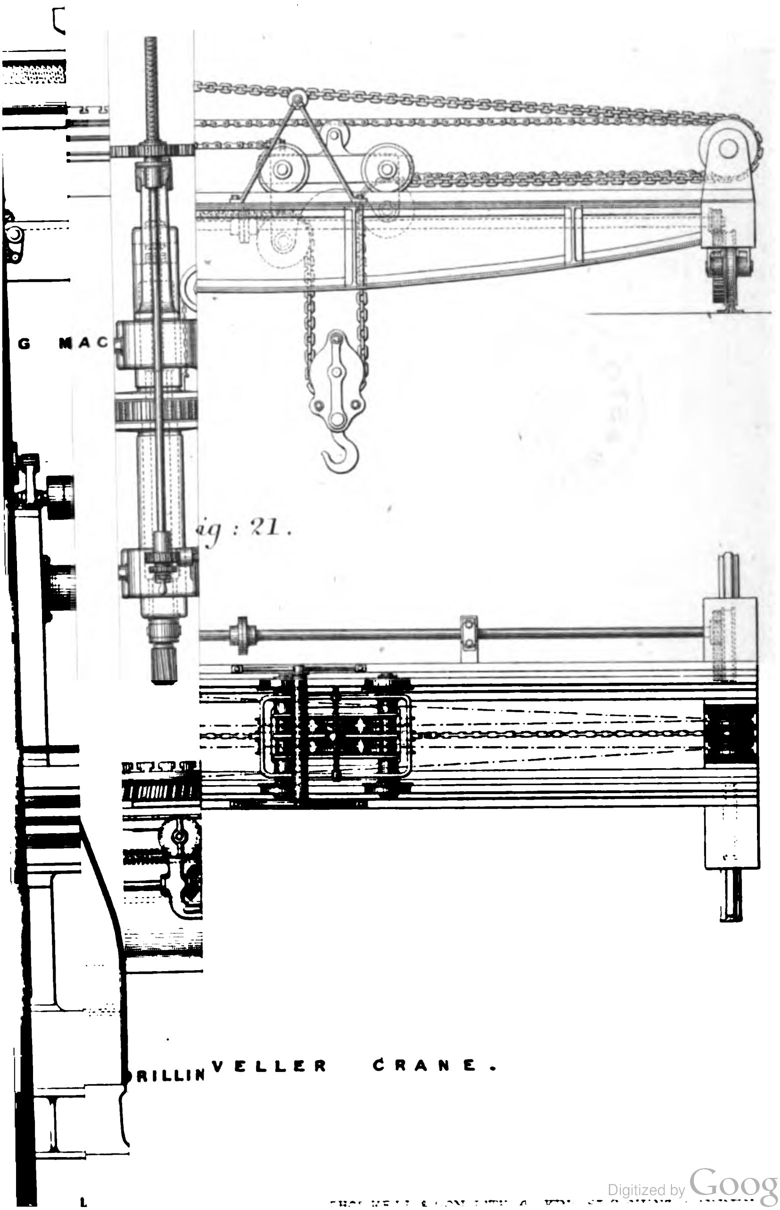

RILLINVELLER CRANE.

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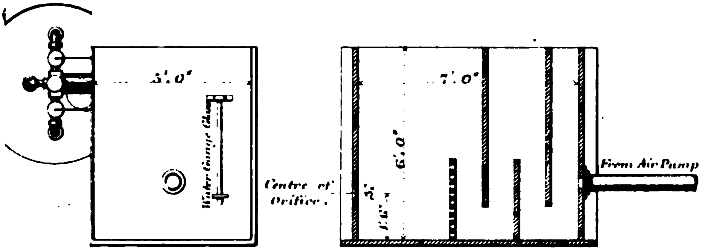
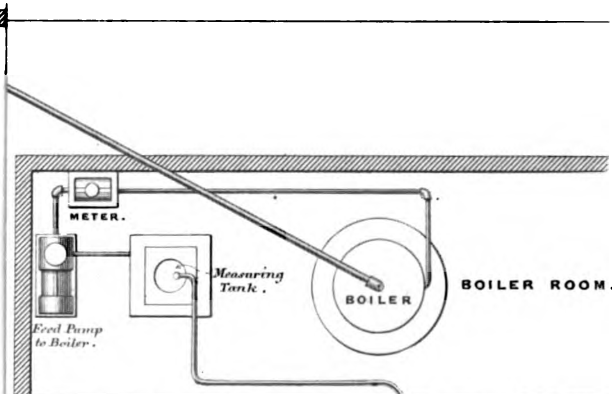


AIR PUMP DELIVERY TANK.

Scale: 6 Feet = 1 Inch.

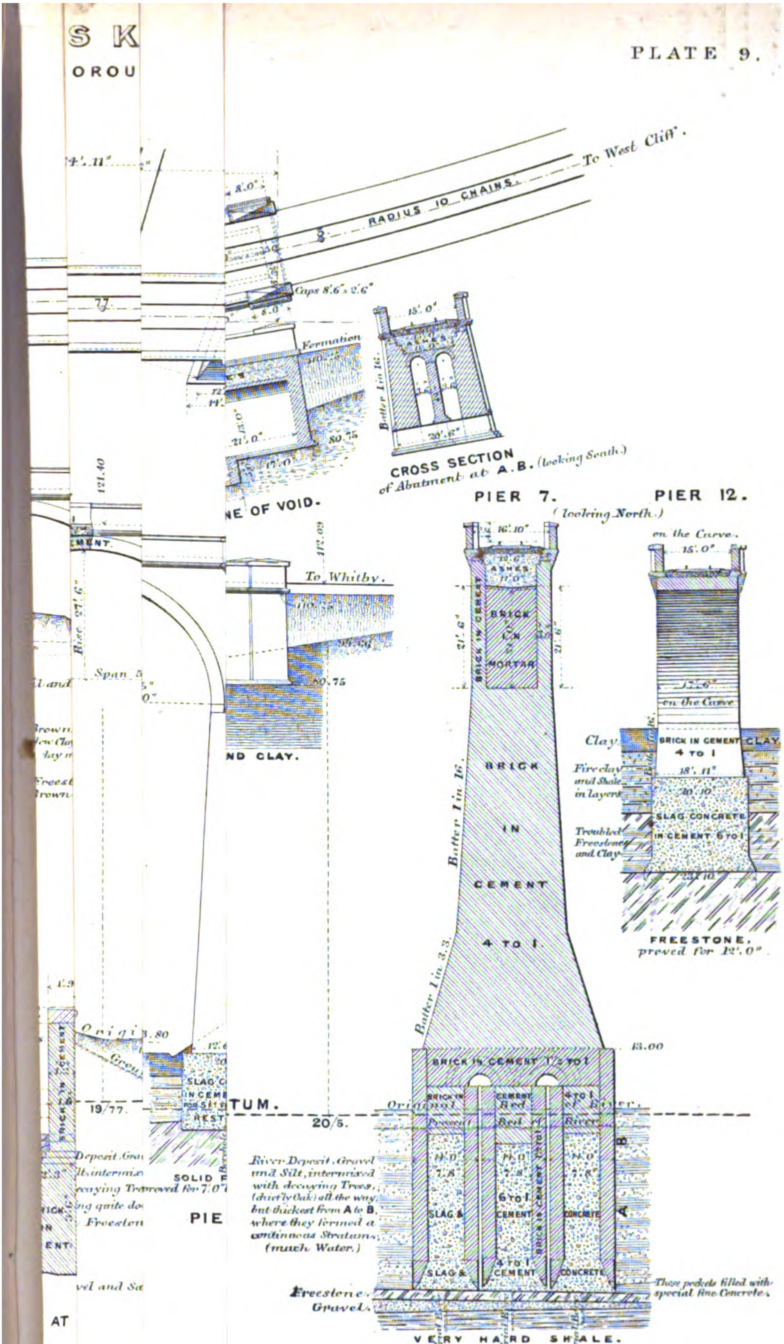
10 Feet.



Scale 12 Feet = 1 Inch.

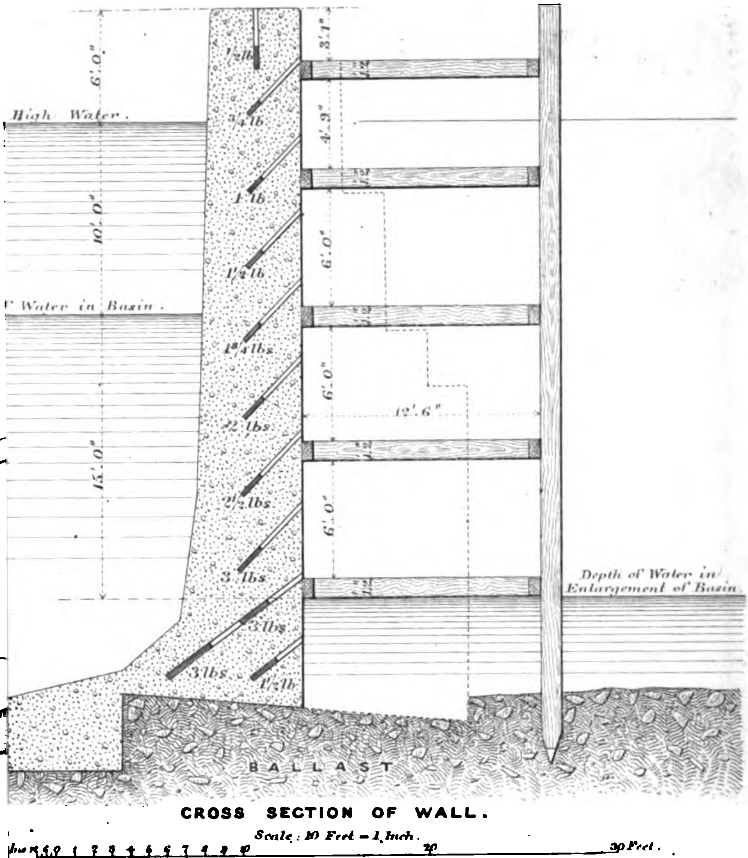
10 15 20 25 Feet.

PLATE 9.



These Cylinders were sunk entirely by grabbing, the river having free access to them; the Trees were cut out by a diver. On arriving at the positions shewn the foundations were cleaned by the diver down to the Freestone, and 4 to 1 Slag Concrete put in by a "pigeon-trap" box up to top of Corbelling, trimmed and stemmed by diver. When this was set, the water was pumped out, and the Cylinders Concreted up with 6 to 1 Concrete, in the ordinary way.

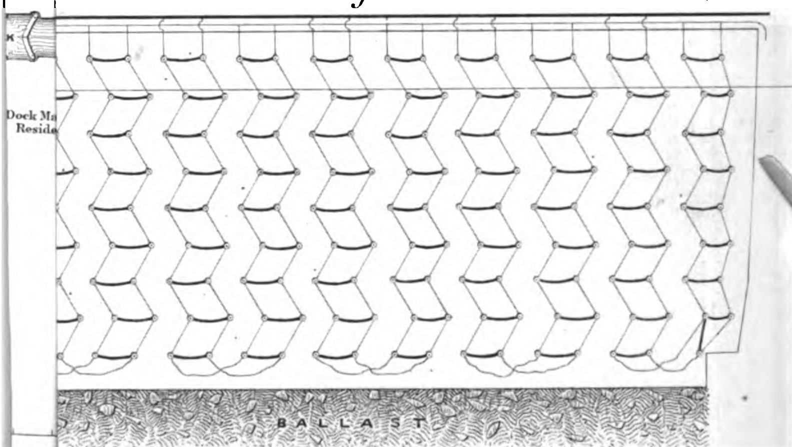
Fig: 5.



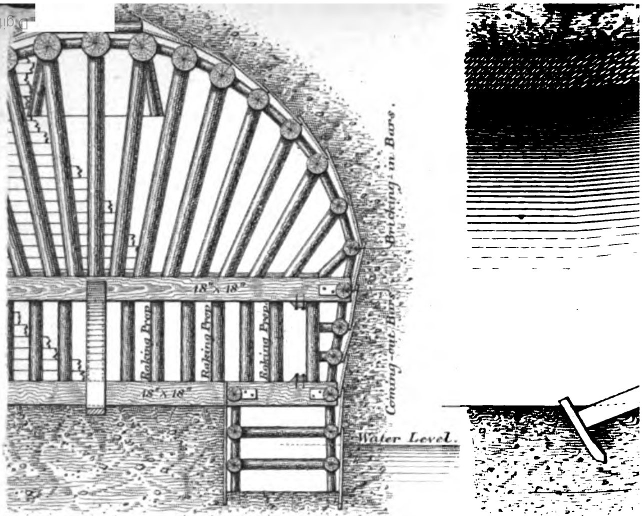
CROSS SECTION OF WALL.

Scale: 10 Feet = 1 Inch.

Fig: 6.



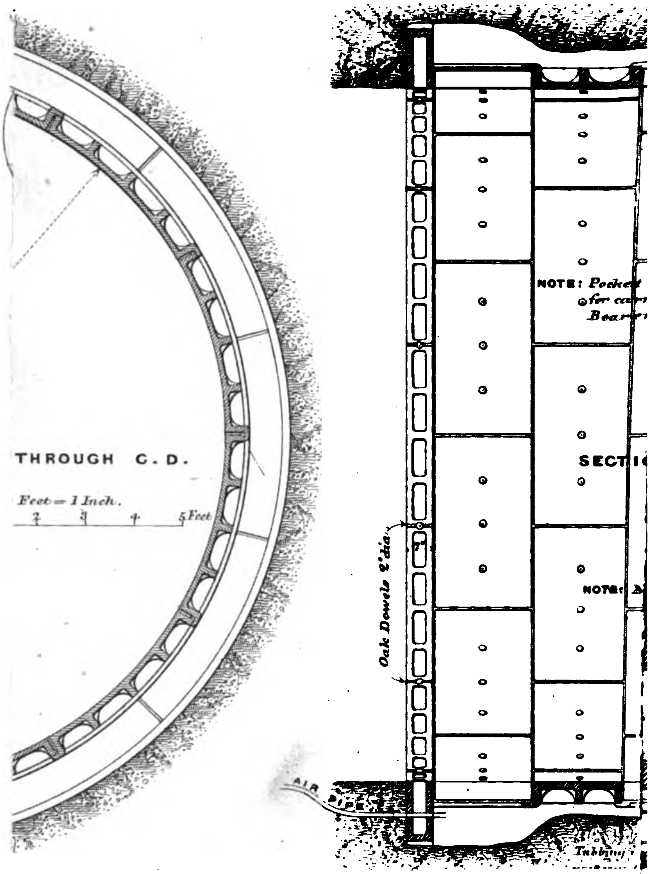
BACK ELEVATION, SHEWING WIRES.



N AT LEADING END OF 9'.6" LENGTH. (in running Sand.)

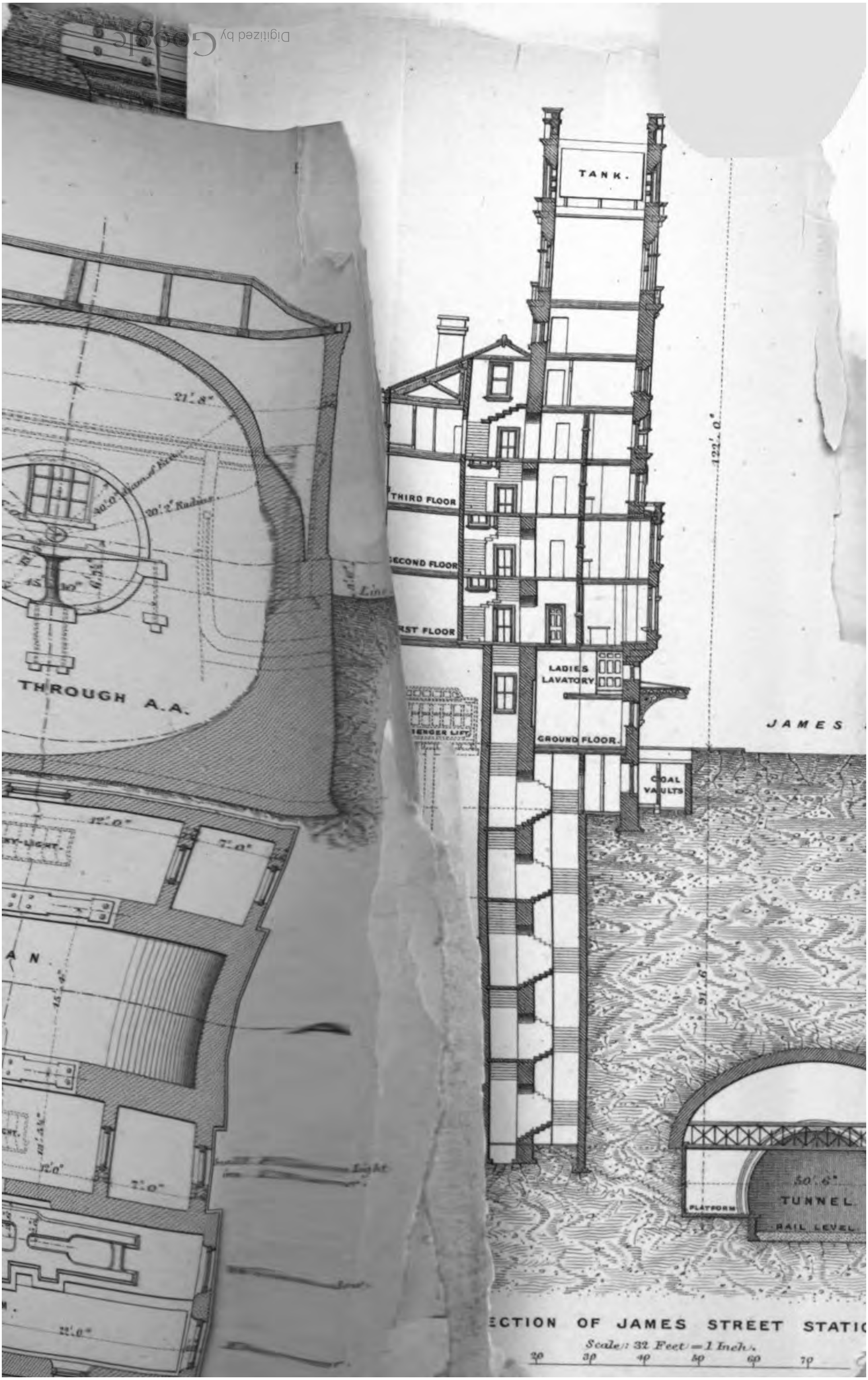
LO

Scale: 12 Feet = 1 Inch.



CLOSE TOPPED TUBBING FOR 15 FEET D

DELT


TANK.
THIRD FLOOR
SECOND FLOOR
RST FLOOR
LADIES LAVATORY
GROUND FLOOR.
SENGER LIFT
JAMES
COAL VAULTS
122'. 0"
91'. 6"
PLATFORM
50'. 6"
TUNNEL.
RAIL LEVEL.
THROUGH A.A.
21'. 8"
30'. 2" Radius
40'. 0" diam. of Base
45°
30°
12'. 0"
7'. 0"
KY-LIGHT.
A N
15'. 4"
12'. 0"
7'. 0"
Light
22'. 0"
ECTION OF JAMES STREET STATIO
Scale: 32 Feet = 1 Inch.
20 30 40 50 60 70